MEMOIRS

OF THE

WERNERIAN NATURAL HISTORY SOCIETY.


GEOLOGICAL
Map
OF THE
LOTHIANS,
BY
R. J. HAY CUNNINGHAM ESQ.^{RE} M.W.S. &c.
1838.
FIRTH OF FORTH
Explanation
OF THE COLOURS.
Transition Series
Red Sandstone Series
White Sandstone Series
Mountain Limestone
Felspar Rocks including Porphyry & Clinkstone
Augitic or Trap Rocks
Isle of May
Bass Rock
Inchkeith
Cramond Island
Lower Largo
Elie
Dysart
Kirkcaldy
Kinghorn
Burntisland
Aberdour
Inverkeithing
North Queensferry
Kincardine
Culross
Borrowstounness
Falkirk
Linlithgow
Leith
Edinburgh
Joppa
Cockenzie
Tranent
Aberlady
Haddington
Dunbar
Linton
Salton
Lasswade
Roslin
Penicuick
Libberton
Gilmerton
Ratho
Whitburn
Blackburn
Bathgate
Carlops
Gala Water
Leader Water
Whitadder Water

CONTENTS.

APPENDIX.

ON THE

GEOLOGY OF THE LOTHIANS.*

BY

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INTRODUCTORY REMARKS.

In offering this essay to the consideration of the Wernerian Natural History Society, the author considers that, for the satisfaction of those to whose scrutiny it is submitted, he is called upon to state some of the circumstances attending its production. The necessary investigations were commenced in the beginning of the summer of the year 1834, and continued with little interruption till the middle of July, after which they were suspended till March 1835; and since that period, up to this date, few weeks have elapsed without more or less time being spent in examination. The deficiencies of the essay, therefore, whatever these may be, cannot be referred to its hasty formation; and if its shortness be considered as hardly agreeing with these state-

* The Wernerian Natural History Society's Honorary Premium of Twenty Sovereigns was adjudged to Mr Cunningham for this Essay.

ments, the author begs leave to mention, that, though the phenomena may have been few which he considered worthy of minute description, this did not (if there was to be an attempt at a geological map of the Lothians) in any way lessen the labour. The country required to be traversed in all directions in search of appearances worthy of description, and if many excursions were made without the author finding any thing to describe, or even a rock of which a specimen was requisite, still there was the same expenditure of time and labour as would have taken place if these excursions had been fraught with interest.

As the Lothians have been traversed in all directions by geologists, little novelty is to be expected in the following pages; yet the author, by verifying and correcting from actual examination all previous accounts, and by adding his own observations, trusts that he will meet the wishes of the Wernerian Natural History Society. From accompanying Professor Jameson in his excursions, he has derived much information, and has endeavoured to conduct his researches on the principles so ably taught by that experienced and celebrated geologist.

The speculative parts of the essay, and the views in regard to some points in the geology of the Lothians, bear on printed statements, and on others which, although not printed, are well known to the geologists of Edinburgh.

The maps accompanying this essay have been coloured, as far as possible, in accordance with Professor Jameson's paper "On the colouring of Geological Maps," which is published in the first volume of the Wernerian Transactions; all the tints, however, have been made more intense,

as the dark engraving of the maps would, in many cases, have rendered the colours, if no deeper than those recommended in that paper, hardly visible.* - The sections have been formed on the same system of colouring, and when other colours were required, those were selected which appeared to harmonize best. In regard to the objects of these sections it may be stated, that they were selected from all those points where the connections of the rocks are in any way interesting. The specimens which accompany the memoir, were selected in the same manner: no rock which the author considered interesting did he intentionally pass. In regard to the paucity of the specimens which have been collected in Linlithgowshire, it may be remarked, that few rocks were found which had not been already noticed in the counties of Haddington and Edinburgh, and, as specimens of these had been selected, the fact of finding the same rocks in a different locality, appeared to render their collection unnecessary.

There still remains to be noticed one circumstance attending this essay, and which may perhaps require explanation; and this is the fact of there being in it no attempt to give details connected with the "*Coal Workings*." The reason which the author had for not entering on this part of the subject was, that he considered that such an investigation lay more in the way of the professional coal-viewer, than of one engaged in purely geological investigations. He did not, therefore, attempt to draw up sections or ground-plans of coal-workings, or to inquire into the quantities of known coal.

* The maps here referred to are those which were lodged with the essay. They were those published by Mr Thomson of Edinburgh.

That his non-attention to this department, however, has in no way been the means of causing him to overlook appearances of interest, in a scientific sense, he is inclined to believe, from the perfect similarity attending the relations of those various beds of coal which have actually fallen under his notice.

THE LOTHIANS.

That portion of Scotland, which is bounded on the north by a line drawn from the Firth of Forth to the Firth of Clyde, is composed entirely of rocks of the Secondary and Transition classes. The former of these is traversed by ignigenous masses of the Felspar and Trap families, while the latter, besides being connected with these rocks, is broken through in several places by different granites and syenites. As it very generally happens that the oldest rocks of a country are those which attain the greatest altitude, while the newer formations which skirt them, form, according to their relative ages, either the hilly or the low land ; so here, the mountainous districts are composed of the older rocks, viz. the greywacke and transition slates (strata, which constitute the more or less uninterrupted high land which extends from St Abb's Head to Port Patrick in Wigtonshire), while the plains and less elevated country, exhibit only rocks referable to one of those groups which collectively form the great series of secondary formations.* All the strata of this class, which occur in the southern division of Scotland, are to be referred to the carboniferous group. In several details these rocks will be found to differ from the

* The geognostical characters of the great high land mentioned in the text were first made known by Professor Jameson, who, indeed, was the first geologist who pointed out the occurrence of Transition rocks in Great Britain.

same as occurring in England; these differences are, however, only such as might be expected to be observable in a deposit extending over a large area: one part of a formation may be more fully developed in one situation than in another, or it may even be entirely awanting. In regard to the mutual associations of the Augitic and Felspathic masses, we may remark that, although no natural sections exhibit the relative ages of these rocks; still, from the examination of other districts, which are partially composed of both; from the circumstance of the trap family being so generally distributed among the carboniferous strata, and also from the eruptions of the trachytes (which may be considered as the modern analogues of the ancient porphyries and felspars), being, in general, anterior to those of rocks having a basaltic character, it is highly probable that the series of felspar masses, which is so generally associated with the Transition deposits, is of a formation more ancient than the basalts and greenstones. In the three counties the geognostical structure of which it is the subject of this paper to describe, extensive districts of both Transition and Secondary strata occur, and, as we have just stated, the higher grounds are composed almost entirely of the older rocks. Before entering upon a minute topographical description of these two great classes, and also before we define their geographical distribution, we shall describe both in a general manner; and as in all geognostical descriptions, it appears to be most natural to follow the ascending series, so here we shall first notice the

TRANSITION ROCKS.

To classify, according to nature, the various mineral masses which constitute the crust of our globe, has been the endeavour of geologists, from that epoch in the history of the science when it was first discovered, that, to arrive at the know-

ledge of the earth's structure, we must have recourse to minute investigation. Many have proposed arrangements of the strata, which they, as the authors, have, of course, considered less liable to objection than those for which they were substituting them. In all these arrangements, there has been no one division of the stratified part of the earth, more universally considered false and unnatural, than that of the "*Transition class.*" It has been said to have no natural existence, but to be the mere creation of minds fettered by preconceived theories. As an objection to the term "*transition*", some have urged that it is one derived from that theory, which affirms, that the rocks of this epoch were formed, during the passage of the globe, from a state unfitted for the existence of organic beings, to one which was calculated for their preservation. If geologists have, in the course of their investigations, come to any certainty concerning the ancient states of our globe, there is certainly no one doctrine supported by a greater number of facts, than that of progressive development. Many remains have been adduced as belonging to beings, which held a place in the zoological scale, higher than was consistent with this theory. With one exception, however, all these remains have been found, on more accurate and better conducted examination, to be, instead of dissentient facts, beautiful proofs of its truth. The exception to which we refer* is as yet, perhaps, unexplained, and by some is considered as a stumbling block which must cause the fall of this theory. If, however, we remember that all the other exceptions have been explained, and that the "*Crocodiles' teeth*" of Burdiehouse, which Lyell considered as indicative of the entire fallacy of this theory, have been found by Professor Jameson, and afterwards by Agassiz, to

* The occurrence of didelphic remains in the slate of Stonesfield, a member of the oolitic series.

belong to fishes; and that the supposed Trionyx of the old red sandstone of Caithness is also found to be a fish ; we may expect that, on more extended investigations, the nature of the Stonesfield remains will appear in no way at variance with their geognostical position. As it seems most accordant with the rules of philosophical induction, to consider that as the best founded theory which is most generally applicable, so one solitary apparent exception should be the more diligently examined ; it ought to be viewed on every side and in all its details, whether it may be reconcilable with the theory against which it appears to militate, rather than be eagerly laid hold of, as a weapon to subvert one derived from apparently legitimate generalizations. To account for the non-appearance of highly organized remains in old rocks, it has been asserted that causes have existed adequate to effect their complete obliteration. " Mechanical pressure, derangements by subterraneous movements, the action of chemical affinity," have all been summoned up to account for the disappearance of animal remains which have (if we may judge from evidence as strong as any attending a science, the facts of which are in few instances open to experiment), perhaps, never been in existence. How fickle in its actions must have been that "lapidifying process"! which could preserve, even to a delicate spine, a frail shell, and be too destructive to allow even the fragment of a bone of a bird or mammiferous animal to be visible in our older secondary rocks! It has been told us, that as the bottom of the existing ocean has not been dredged "throughout an area co-extensive with that occupied by the carboniferous rocks," thus enabling us to calculate the chances which will bring up the relic of a mammifer ; so the fact of the non-appearance of these remains ought not to be considered as a proof of their non-ex-

istence. But, as has been well remarked, "Every island, every continent, has formed part of an ancient bed of the ocean, and this ancient bed is exposed to the examination of thousands of observers in every degree of latitude not covered by polar snows." Further, on finding this statement in a work which proposes a classification of tertiary strata, however ancient, by merely acquiring a knowledge of the extinct and existing species contained in each, are there not marks of inconsistency? It is reckoned unsafe to judge of the utter absence of highly organized animals, in very old strata, by their not having as yet been found; while the fact of a tertiary system of strata containing a greater percentage of extinct shells than another, is considered as perfectly demonstrative of its greater age. We are not wishing to inquire whether, in these instances, such a mode of examination will infallibly lead to a just conclusion or not; but it appears to be drawn as an inference from appearances precisely similar to those, which have induced geologists to believe in a progression of development. As an argument against the doctrine of progressive development, it has been affirmed that the corals and mollusca, which lived in the ancient seas, were not of a more simple structure than those which at present exist. Those, however, who advocated the opinion that, from the oldest fossiliferous deposit to the formations of our own epoch, there were proofs, from examining fossil bodies, that the standard of organization was gradually, and not instantaneously, raised, never, either directly or indirectly pronounced, as their opinion, that this "progressive development" of organized beings was evinced by comparing the members of any one genus, as they occurred in consecutive formations. It was never affirmed, as far as we are aware, by any geologist, that, if a certain natural class of organized fossil remains was observable in several forma-

tions, (the relative ages of which were indicated by superposition) we must expect to find in the oldest of these formations or series of strata, individuals of this natural class having a more simple structure than those imbedded in the newest. But it was insisted, and is yet (though some imagine that they see in the laws which now govern organized bodies in all their relations, and in the globe itself, an almost eternal and uniform system of legislation), that the earth's strata exhibit proofs from their contents, that certain epochs have been characterized by the creation of the several main links of the zoological chain.

The term "Transition" has been discarded by a celebrated geologist upon another ground; but unfortunately the reason why the term was applied has been misunderstood. Mr Phillips, in his "Guide to Geology," after saying, that some geologists make a Transition class of rocks, affirms "that this is needless, for such passages are not thought necessary to be marked in other instances." When Werner named a certain class of rocks "Transition," it was done, not from discovering that they passed into the inferior or more crystalline rocks, but from the conclusions which he drew from finding, that, in this series, for the first time, marks of animal and vegetable life occurred; and that these were remains of beings which possessed a structure of the most simple nature. He so named this series of rocks, not because it passed by mineral character, or alternation, into his "Primitive class;" but because his examination of its contents, and relations to associated rocks, made him draw the inference, that it had been formed during the passage of the globe, from a state in which vegetable and animal life existed not, to one fitted for its preservation.* The term "Transi-

* "They are supposed to have been deposited during the passage or transition of the earth from its chaotic to its habitable state."—*Jameson's Geognosy, p.* 146. *Edinburgh.* 1808.

tion" was theoretical; but it is upheld by as many proofs as any other acquired portion of geological knowledge. As regards the objection to the term Transition, that it is unnatural, inasmuch as the rocks of this class pass into the inferior and more crystalline strata, and in the upper parts into those of secondary formation, it may be asked—Where is the series of rocks, which, however distinct and separate from its associated formations it may appear to be in one country, has not been observed in other localities to alternate with and pass into them? If in all cases, however, these appearances were considered hostile to forming arrangements of the globe's strata into great divisions, it is evident that no classification could be formed from the relative superposition of strata, and that one from some other system of phenomena would be necessary. Though these transitions of strata into each other, however, are conspicuous, there is still no reason why such transitions should be considered as affording a reason that from "gisement" strata should not be arranged. When viewed on the large scale, that on which all geological appearances ought to be viewed, the series which, from superposition, is to be acknowledged as of one formation, is also, from its being characterized by one or more classes of fossilized organic bodies, and in many instances by a wonderful similarity of mineral character, to be considered as the uninterrupted production of a certain geological epoch. The mineral characters of the transition rocks which occur in the Lothians, are limited. The Greywacke is, in general, a fine aggregate of minute grains of quartz and Lydian-stone, imbedded in a base approaching to clay-slate, and containing scales of mica very generally distributed through it. In size, the components of the greywacke vary; they occur of all magnitudes, between that of the smallest sand and a fine

conglomerate; and, when very compact, its mechanical nature is not very easily recognised. The Clay-slate, which is frequently associated with the greywacke, into which it passes, and with which it alternates, is of various shades of ash, bluish and smoke grey. Its general aspect is earthy, and it never assumes that crystalline appearance which eminently characterizes that of an older formation, viz. the slate associated with gneiss and mica-slate. In the strata of greywacke there is also sometimes a striped appearance, identical with that exhibited by the coal formation shales, and, in some districts, it contains numerous minute veins of massive quartz, and layers of red hæmatite. The uniform sameness of the mineral characters of the Transition rocks, in countries far removed from each other, is a proof that the causes, from the actions of which they resulted, were almost universal; a fact which is at complete variance with that system of geology, which sees only in the various rocks of our continents the long-continued action of existing causes. By the term "universal," however, it is not intended to be implied that at one period the earth was covered completely by an envelope of greywacke strata. Such an opinion, either in regard to it or any other formation, is contradicted by every appearance. But it is wished to be only understood as intimating that, during the epoch of the greywacke's formation, it is probable that, when depositions of strata took place over the globe, they were in circumstances which allowed only the deposition of a greywacke. The idea which supposes, that, if a deposition of strata took place, that deposition must in all parts be similar, because there existed a series of causes over the whole globe, which if called into action produced the same effects, is quite different from that which assumes that these causes acted at one given period over the whole globe. If all

the deposits at present forming below the waters of the ocean, could be looked upon in one wide extended plain, it would be found that their mineral characters are so different in different places, that little similarity could be traced amongst them. That deposit which resulted from the erosion of a granitic district, would present the characters of various red sandstones; that which was produced by the comminution of quartz rock, would approach in character to a white sandstone; while the formations which were formed from the disintegration of secondary or tertiary districts, would consist of various alternations of sands, gravels and clays. In all these supposed cases there is nothing similar to that uniformity of mineral character which is conspicuous in older formations; a fact which indicates that the causes effecting these formations were very general, and that similar circumstances existed over an immense portion, if not over all the globe at one period.

SECONDARY ROCKS.

Having now noticed generally the transition rocks of the Lothians, we shall next describe that series of Secondary strata which forms almost the whole of the counties of Edinburgh, Haddington, and Linlithgow. The Secondary series of the Lothians is not composed of one and the same rock, but is, on the contrary, an example of a compound formation, inasmuch as it is an assemblage of red and white sandstones, variously coloured shales, and limestone, all of which are so associated with each other, that their synchronism of deposition is conspicuously evident. The white sandstone group of the Lothians has, as we have before stated, always been considered as belonging to the Independent Coal Formation. This series differs in several respects from the coal-measures of England. It would certainly indicate a

state of things entirely different from the present, if a formation, whose relative position in the crust of the globe was in one country correctly ascertained, exhibited in every other a strictly uniform sameness in its mineralogical and fossilogical characters. If contemporaneous formations were identical in all their details, the determination of strata would be conducted in a manner far different from what it is. Instead of traversing extensive districts, examining the relations of an unknown rock to others whose natures were apparent, and from superposition and other characters ascertaining geological equivalents, the mere view of a characteristic specimen would be sufficient ; and from geology being one of the most intellectual of Sciences, one which requires minute investigation, it would deserve hardly to be considered as an Art.

Authors, in describing that series of rocks which lies, in the regular succession, below the magnesian limestone, and above the transition formations, divide it into the Old Red Sandstone, Mountain Limestone, and Coal Formation, drawing lines of demarcation between all these deposits. Though, from observing, in some countries, that the position of one or all of these deposits is so unconformable, that it is only to be accounted for by the state of repose which existed during their several depositions, having been interrupted by disturbing causes, still there is no reason to conclude that this unconformability is to be observed in all countries. This is to assume, that igneous actions in the early ages of the world, differed entirely from those which now operate, and also that the upraisures of contemporaneous strata were themselves contemporaneous. A deposit which is completely separated from that which succeeds it in one country, may in another make a transition into it by numerous alternations; and thus we have a proof that breaks in the sequence

of strata, are, if viewed with the extent of the globe, only local. In the Lothians the divisions of old red sandstone, and mountain limestone, are unnatural; for strata which, in one locality, might, from their relations to others, be considered as the old red sandstone, are, in another, found to occupy a position which renders this impossible. If these sandstones are found both above and below the mountain limestone, and are frequently seen to alternate with it on the large and small scale, it is evident that they form one deposit; that the causes which produced them were not interrupted by paroxysms of violence. In the Lothians and in Fife, there are many points which evince that the old red sandstone, mountain limestone, and coal formation, cannot, as developed in these districts, naturally be separated.

Professor Jameson, in his Mineralogical Account of Dumfries-shire, p. 165, enumerates several localities in the Lothians and in Germany, where red sandstone is found intimately connected with the white sandstone series. In regard to the occurrence of red and brown sandstone, the Professor states, "1st, In lower Silesia, nearly the whole of the coal-field is composed of reddish-brown and cochineal coloured sandstone, with which great beds of coal alternate. 2dly, In the coal-field of Mid-Lothian we have the following instances of similar coloured sandstone occurring in the coal formation: *a.* In Dryden Water, near Loanhead, there are several beds of reddish-brown coloured sandstone, accompanied by similar coloured ironstone in the coal formation. *b.* Near Mr Cameron's paper-mills, on the banks of the Esk, there are thick beds of reddish-coloured sandstone, that evidently belong to the coal formation, and the same rock continues in the direction of the river, forming the picturesque cliffs of Hawthornden and Roslin, and extends even to Auchindinny Bridge. *c.* Immediately behind themanse of Collinton there is a beautiful section of the

coal-field. The strata are semicircular and have their convexities uppermost, or form what is called a *saddle*; they are of a reddish-brown colour, and alternate with layers of greyish-black coloured slate-clay, and reddish-brown coloured clay-ironstone. On each extremity of the saddle rest the more common rocks, viz. grey-coloured sandstone, globular clay-ironstone, &c. *d.* The rock on which Craigmillar Castle is situated, belongs to the coal formation of Mid-Lothian. It is composed of horizontal beds of greyish and reddish-coloured sandstone, that alternate with their beds of reddish-coloured slate-clay and limestone conglomerate. *e.* The hill of Salisbury Crags belongs to the coal formation, and in it we observe repeated alternations of reddish-coloured sandstone, clay-ironstone, slate-clay, and limestone conglomerate."

In Fife, the coast between Dysart and Wemyss exhibits four alternations of the red with the white sandstone; and in the course of the Bevelaw Burn, a small stream which runs for a few miles at the base of the Pentland range, the white sandstone underlies the red. In other quarters this arrangement is completely reversed; as on the coast of East Lothian, between the Cove and Dunglass Burn, where the white coal-sandstone overlies the red. By following the courses of the Dunglass, Bilsdean, and Thornton burns, the transitions of the white sandstone series into the red, are most satisfactorily displayed; the strata, as they recede from the sea, gradually assuming a red colour, till, at last, they pass into the red sandstone. In that part of the Esk river which runs past Arniston and Kirkhill, there are numerous alternations of the red with the white sandstone. Much also of the country intervening between Drummore-mill and Hawthornden, through which the Esk flows, is formed of the same red sandstone: its relations, however, to the white sandstone, are evident, and exhibit nothing fitted

to justify the misconceptions of some who have examined it.* The mountain limestone, which, if it preserved that position which it is generally found to occupy in other districts, would be a formation separating the white from the red sandstone series, occurs in the Lothians connected with both. While making these statements indicating that the causes which produced the Secondary formations of the Lothians were uninterrupted during the deposition of the series, and that this circumstance accounts for the various alternations of its members, we may remark, that there has been a source of error in the belief, that in all instances three distinct deposits,† viz., the Old Red Sandstone, the Mountain Lime-

* Dr Hibbert, in his paper "On the Limestone of Burdiehouse," published in the Transactions of the Royal Society of Edinburgh, vol. xiii., page 137, affirms, that, by ignigenous action, "there has been an emergence of beds even inferior to the carboniferous group," and cites the Pentlands and the coast of North Berwick as localities. The strata exposed there, however, are all of the same general nature as the red sandstones of other places, which, by their relations to the white sandstones, so clearly indicate that both series constitute one contemporaneous formation. The red sandstone of Hawthornden, exhibited also to Dr H. some appearances which caused this observer to believe that it had been deposited soon after the formation of the Transition rocks. In regard to what these were we are ignorant; but if viewed in all its relations, it will be found to form only one of those deposits of red sandstone, which, with those of white sandstone, coal, and shale, form the secondary system of the Lothians, and geognostically represent the coal formation.

† As an instance of this we may mention the conclusions to which Messrs Sedgwick and Murchison came, after examining the secondary formations of the island of Arran. In that island two red sandstones occur, the one above, the other below, the strata of white sandstone containing beds of coal, while the Mountain Limestone occurs interstratified with both. After examining this district, these geologists were led to consider that series of red sandstone strata, which was in the more immediate vicinity of the old rocks, as the Scottish representative of the old red sandstone of England: the assemblage of white sandstone was by them described as the Coal formation; while the red sandstone which lay above it, was stated to be the equivalent of the new red sandstone of England, differing from it, however, in this circumstance, that in Arran it was conformable with the coal formation. By

stone, and the Coal Formation, separate, without ever blending into each other, the New Red Sandstone from the Transition Rocks. It is this alone which has made some declare that the series of red sandstone strata, which, in some places, is found above the true Coal Deposits, belongs to the New Red Sandstone. To determine the age of strata, they must be examined through their whole extent, and their position in the globe's crust is only to be ascertained by studying all their various phenomena. Though the red sandstone, white sandstone, and limestone, of the Lothians, may not, from the circumstance of their being so intimately connected, be considered exactly similar to the carboniferous series of other districts, though, perhaps, they exhibit not that invariableness of position which characterizes them elsewhere, still, in the circumstance of the red sandstone and conglomerate being most remarkably developed in those parts of the country which are in the vicinity of the older rocks, they exhibit an appearance similar to that observable in other and more distant localities. The conglomerates of the lower parts of the series are, from the size of the masses which compose them, highly indicative of the great mechanical action which must have operated in their formation.

Though conchological contents characteristic of a formation, the position of which relatively to others is known, be found in districts at a great distance from those in which the

By comparing this series of red and white sandstone with the same as developed in the Lothians, or even in the adjoining coast of Ayrshire, the identity of the two is easily made out, and that sandstone which was by these gentlemen considered as the new red sandstone, becomes only a member of the great secondary series of the Lothians, no one of which can be naturally separated from the others, if throughout the whole extent of their distribution we examine their mode of arrangement relatively to each other. This view of the sandstone of Arran was proposed by Professor Jameson, in one of a series of memoirs on the geology of Arran, read to the Wernerian Society several years ago.

deposit of an understood geological age occurs, still we are not to consider that these far separated deposits must necessarily be of the same age. That they may be, is possible, but it is as probable that they may not, and their evidence is never to be opposed to that affordedby superposition.

That the red conglomerates and sandstones of the Lothians are not derived from the consolidation of sands and rolled masses brought from a great distance, is apparent, from the fact that no rock-fragments are found in them, but such as occur *in situ* in their more immediate neighbourhood. That vast deposit of red sandstone conglomerate which skirts continuously the Greywacke formation of the Lammermuirs, from Redheugh in Berwickshire to Heartside in Haddingtonshire, and which rises into mountain masses in several parts, is entirely composed of variously shaped rolled masses of greywacke and transition-slate. Besides containing masses of the stratified or Neptunian rocks, on which the conglomerates rest, they also, though rarely, include rolled masses of members of the felspar series. In the red sandstone hill of Chesters, near the village of Spott in East Lothian, masses of felspar-porphyry occur, and, in the conglomerates of Carlops and Habbie's How, fragments of compact felspar are abundant. These appearances therefore indicate that all the members of the felspar series of the Lothians are not newer than the carboniferous formations; but prove, on the contrary, that by being subjected to aqueous attrition, they have contributed to the formation of these strata. The white sandstone series, which alternates with the red, and has been entitled The Independent Coal Formation, is, like the red sandstone, compound; it is an assemblage of white sandstones, slate-clay, bituminous shale, clay ironstone, and coal. In the Red Sandstone series, the sandstone is in ge-

neral of a bright red colour, and conglomerates are abundant; but, as the name implies, those of the white sandstone group are generally white, and conglomerates are comparatively rare. The shales accompanying the red sandstone strata, are of various shades of blue, green, yellow, and red; while those associated with the white sandstone are generally grey: bituminous shale also is very rare in the former series, while in the latter it is largely developed. The abundant diffusion of coal beds in the white sandstone series, is another characteristic feature of this group, for when these do occur connected with red sandstone, they are, with few exceptions, situated in what may be considered as a debateable ground between the two classes of strata, and in those portions which partake of characters of both. Another rock which we have mentioned as occurring in the Lothians, is the Mountain Limestone. This, as we have previously stated, is not here, as in those districts of England or Ireland where it occurs a distinct and separate formation. It occurs in the red sandstone series of the Lothians, forming, in some localities, considerable beds, but its comparative scarcity in it is to be considered as a mark eminently distinguishing this series from that of the white sandstone group.

Having now described the general relations of the various secondary rocks of the Lothians to each other, we shall enumerate their several mineralogical ranges of character. The red sandstone, which we have mentioned as the frequent occupant of the lowest part of the series, is in general a fine aggregate of grains of quartz and felspar, held together by a basis of ferruginous clay; scales of mica are profusely distributed through it, and frequently, by their great abundance, it assumes a slaty structure. A coarse conglomerate forms a part of the red sandstone se-

ries. It is of two kinds; one variety, as we have before stated, being entirely formed of variously sized masses of greywacke and its slates, and occurring in immediate connection with the transition ranges of the Lammermuirs; while another, which is met with only in different parts of the Pentland district, and in the neighbourhood of Pennycuick, is composed of rounded masses of quartz-rock, greywacke, flinty-slate, felspar, and common jasper, imbedded in a base of similar fragments. At Danskin, in East Lothian, and in the mountain valley of Glencorse, both conglomerates are well marked. The hills which occur on both sides of Dunglass Burn, are composed of this rock, which has resulted from the disintegration of the greywacke, and the masses which form it are on such a colossal scale, and held together so very loosely, that it might be mistaken for a formation of very modern date. The red sandstone forms extensive districts in Berwickshire, and much of that part of East Lothian which ranges along the northern front of the Lammermuirs. As that of several other parts of Scotland, the red sandstone of the Lothians is eminently characterized by containing in many places numerous circular yellowish-green markings, in the centre of which there is frequently a black coloured spot. Though red is the predominating colour of the red sandstone series, still, associated with it, there are other sandstones of various shades of brown and grey. Variegated sandstones are abundant, brown or red markings occurring in a field of white sandstone; as examples of these, the sandstones of Salisbury Crags and Dunbar are conspicuous. Interstratified with the shales of the red sandstone series, clay-ironstone sometimes occurs; it is, however, perfectly different in its characters from those clay-ironstones which are so abundantly interstratified with the white sandstones and shales of the white

sandstone group; it is in general of a brick-red colour, and contains a considerable proportion of calcareous matter. Unlike the clay-ironstone of the coal formation, that of the red sandstone series never exhibits an internal structure, and is characterized completely by the circumstance of its never containing, as the former frequently does, an organic nucleus.

The white sandstone of the great carboniferous group is composed of minute grains of quartz, held together by a ground of argillaceous or calcareous matter: mica is often present, and, as in the red sandstone, frequently produces a schistose arrangement. Felspar, which is very generally distributed through the red sandstone in grains, is in the white far more sparingly disseminated. Bituminous matter occurs in great abundance in the coal sandstones, and frequently is so equally distributed as to cause them to assume a black colour; whereas in the other sandstones, it forms only small layers, which are arranged in positions parallel to the planes of stratification. By containing large rock fragments, this sandstone sometimes becomes conglomerated; these conglomerates are, however, seldom so coarse as those associated with the red sandstones. The fragments are jasper, quartz, Lydian stone, compact felspar, and flinty-slate, imbedded in an aggregate of smaller masses. At Liberton Brae, a conglomerate associated with the coal sandstone contains fragments of red sandstone, varying in size from the smallest dimensions to the bulk of a man's head.

The slates which accompany the white coal formation sandstone are of two kinds,—Argillaceous Shale or Slate-Clay, and Bituminous Shale; neither of these, however, possess a wide range of mineralogical character. The former is in general of a grey colour, while the latter is most

frequently of a black, or blackish-brown, containing occasionally minute scales of mica. The colour of these two slates is not uniformly sufficiently indicative of their distinct natures, and as it is highly necessary, in an economical point of view, that they should be easily recognised, we may remark, that in the streak we have a character which at once decides them. The slate-clay has a streak without lustre and of a grey colour, while that of the bituminous shale has a resinous lustre and a brown colour. The bituminous shale frequently makes a transition into coal; examples of which are to be observed on the shore below Kirkaldy and Dysart.

Clay-Ironstone, the next member of this series, is possessed of several characters which render its examination a subject of considerable interest. The clay-ironstone has in general a blackish-grey colour, with a conchoidal fracture and no lustre; it occurs in two positions, either as strata of inconsiderable thickness, alternating with the several members of the coal formation, or in rows of spheroidal lenticular masses, imbedded in shales, and arranged in lines parallel to the direction of the strata. On fracturing the lenticular concretions of ironstone in a direction parallel to that of the strata containing them, there is generally to be observed an internal structure; this structure consisting of a series of veins of calcareous spar, diverging from a central point with more or less regularity, which series is crossed by another arranged round the centre of the clay-ironstone. The veins which produce this structure are generally composed of calcareous spar, which is associated, in some instances, with quartz and elastic mineral pitch; they all decrease in size from the centre to the circumference, being at their origin often sufficiently wide to allow of the crystallization of the spar in its usual forms. That these

veins are of a contemporaneons formation with the clay-ironstone in which they are contained, is an opinion adopted by Dr Hutton and also by Professor Jameson, the one reasoning on Plutonian, the other on Neptunian, principles. Ichthyolitic coprolites are abundantly distributed throughout the lenticular masses of clay-ironstone, and specimens may easily be procured bearing more or less perfect intestinal impressions. In the Edinburgh Philosophical Journal, vol. xxxii. p. 165, analyses of two of these interesting organic relics, by Dr W. Gregory and Mr R. Walker, are published. The results of these analyses we may here subjoin.

1. Analysis of a Coprolite found in Clay-ironstone, Wardie.

Organic matter, Sulphuret of Iron, Siliceous matter,	4.134
Carbonate of Lime,	61.000
Carbonate of Magnesia,	13.568
Oxide of Iron with a little Alumina,	6.400
Phosphate of Lime,	9.576
Fluoride of Calcium, Oxide of Manganese,	a trace
Water and loss,	5.332
	100.000

2. Analysis of a Coprolite found in Clay-ironstone, Fifeshire.

Matter insoluble in Muriatic Acid and chiefly organic,	3.380
Carbonate of Lime,	24.255
Carbonate of Magnesia,	2.888
Phosphate of Lime,	63.596
Water,	3.328
Phosphate of Magnesia, Oxide of Iron, Oxide of Manganese, Fluoric Acid,	trace.
	97.447

Besides containing coprolites, the clay-ironstone of the

Lothians, in many instances, envelopes beautifully preserved fishes, while at other times it contains only teeth and scales. Remains of plants, as in all the other members of the coal series, occur in considerable abundance in the clay-ironstone, and on a favourable fracture, they in many instances exhibit, in the most perfect manner, numerous and well preserved relics of the flora which existed at that early period when the coal-beds were deposited. In regard to the position of the organic bodies in the ironstone concretions we may remark, that they are invariably disposed parallel to the longest diameter of the mass, an arrangement which agrees completely with a deposition from a state of mechanical suspension in water. We have before noticed that the nodules of clay-ironstone are arranged in layers parallel to the direction of the strata in which they occur, and as the shape of these masses is a sufficient indication that they could not have been so disposed in any strata but such as were originally formed in a horizontal position, we have, when these lenticular concretions occur in vertical or highly inclined strata, an evident proof that these strata have been altered. The clay-ironstone, which occurs at Wardie, near Newhaven, has lately been analyzed by Dr W. Gregory of Edinburgh (Edinburgh Philosophical Journal, vol. xxxv. p. 173). Two of the specimens which were examined by this chemist were found to have the following composition in 100 parts:—

1. Matter insoluble in acid sand,	196	
Peroxide of Iron,	125	
Alumina,	35	
Lime (a trace).		
Moisture and Loss,	44	= 100
2. Insoluble matter,	388	
Peroxide of Iron,	564	
Alumina,	25	
Lime (a trace).		
Moisture and Loss,	33	= 100

The limestone which is associated with the red and white sandstone formations of the Lothians, exhibits, throughout its whole extent, a very limited range of characters. It is usually of a grey colour, of different degrees of intensity; its fracture is more or less conchoidal, with an earthy aspect. In some quarters, as at Salton, Linton, and Sunnyside, the same limestone occurs of a reddish-brown colour. In several localities, as at Bathgate in Mid-Lothian, the limestone is associated with hornstone; this mineral forming in it numerous contemporaneous imbedded masses, containing in some places silicified madrepores. At Linton, jasper occurs similarly connected with the limetone as the hornstone. The mountain limestone, in those quarters where it is extensively worked, exhibits frequently several alternations of a compact rock, with one having a more or less perfect slaty structure, and containing a larger quantity of argillaceous matter. It is in this imperfect limestone that vegetable and animal remains are found in the greatest abundance, and in certain districts it is characterized by particular fossil bodies. At the Rhodes Quarry, near North Berwick, the limestone becomes highly fetid. This is the only point where such an appearance is to be observed on a large scale, though, in several localities, as at Salton, the same may be observed in one or more parts of a stratum.

In their organic contents the secondary strata of the Lothians are in some respects remarkably interesting, and the shortness of our remarks connected with them is not to be considered as indicating that these interesting bodies ought not to receive much attention from naturalists. Their structures, when viewed comparatively with living races, have unfolded many highly valuable portions of knowledge in regard to the ancient temperatures of our globe, its waters, and the circum-

stances under which its strata were deposited. The arriving at the conclusions, however, to which the study of organized fossils leads, presupposes a complete knowledge of all the kingdoms of existing nature,—an acquirement which never has been, and probably never will be, centred in one observer. As a knowledge of the natural history of the organic world cannot be obtained but by the exertions of men devoting their energies exclusively to its several grand divisions; so to these the geologist must refer, for details connected with the structure and other relations, of the animal and vegetable relics which he discovers in his investigations. The immediate duty of the geologist, in regard to fossil remains, is, to examine their relations to the several strata of the formation in which they occur, and the connection of that formation with others; while it is the department of the zoologist and botanist, and the most difficult, arduous, and philosophic part of their studies, to discover the nature of these remains, and, from the present conditions of similar living beings, to speculate on the state of the world as connected with temperature, and the distribution of land and water in those epochs when the fossil species enjoyed life. To acquire a knowledge of the ancient world, there must be a division of labour: the examination cannot be conducted by one; but, in this great work, there is required the combined efforts of a Werner, a Cuvier, a Brongniart, and an Agassiz. In this state of things, our remarks will be on this subject sufficiently brief.

Throughout all the various members of the white sandstone series of the Lothians, the remains of vegetables occur, and it is there only that they are to be met with. In the red sandstone series there is, in the circumstance of layers of bituminous matter, occurring in the sandstone, an indication that these strata had been formed, after the creation of vegetables, and we have never found any more marked proofs

of their existence. In the Transition rocks there is only one locality in which organic relics have been discovered; we refer to the contents of a limestone connected with this series which occurs at the Crook Inn, in Peebles-shire. The fact that well marked vegetable remains are not to be observed in strata older than the white sandstone series, or in any of the alternating groups of red sandstone, is well exemplified in that part of the coast which extends from Redheugh in Berwickshire to Aberlady in East-Lothian. On examining this portion of the country, we pass over in succession examples of each of those stratified deposits which occur in the southern division of Scotland. After leaving the Transition rocks and the red sandstone which rest upon them, we, near the Cove, meet with the carboniferous strata, and the mountain limestone, and then, for the first time, observe fossil vegetable remains. Near Dunbar, the white sandstone is succeeded by a group of red sandstone strata, which is as destitute of any fossil relics as that which rests immediately on the older rocks. Near Goolan, the coal strata again appear, and, with them, vegetable fossils. From the non-occurrence of fossil vegetables in the red sandstone, however, the conclusion can never be drawn that these sandstones are of a formation anterior to the creation of plants. It is, however, indicated, that there were, in the formation of the red sandstones, causes which did not allow the deposition of vegetables. The rocks from which they are derived may not have been covered with a vegetation so luxuriant as those, which, on decomposition, formed the white sandstone, or their deposition may have been attended with unknown actions, adequate for the destruction of such remains. Throughout the Lothian district the vegetable features of the strata observe the same general appearance, and are indiscriminately scattered through the several strata of the white

sandstone series. The plants which do occur, though, perhaps, some may be unknown in other coal-fields, present, however, a general similarity to those of similar districts. The *Sphenopterides*, the *Lepidostrobi*, *Sigillariæ*, *Stigmariæ*, *Lepidodendra*, and *Lepidophyllites*, abound in numerous localities, often in a state of the greatest preservation, and in others there have been found trunks of gigantic members of the *Pine tribe*. The remains of this class, found in the sandstone of Craigleith, are well known, and their structures have been completely unfolded by Mr William Nicol, as stated in a memoir in the Edinburgh New Philosophical Journal,* the result of which is, that all belong to *coniferæ*, a series of vegetable bodies which that observer has found to form, without any intermixture with *dicotyledons* or *monocotyledons*, all the great vegetable stems of the Independent Coal Formation. Concerning the states in which these fossils are found, it may be remarked that they are more or less bituminated, some portions even being changed into coal; and that Professor Jameson, in his lectures, states it as his opinion that the vegetable matter in these fossils occurs sometimes but slightly changed, so that the earthy matter may be removed by chemical agency, leaving the wood but little changed as to structure and composition.

The fossils detected in sandstone, are most frequently found in the state of sandstone, and the whole of the vegetable structure having been removed, nothing remains to indicate their nature but the external form. The causes which have effected these changes are unknown, and the discovery of them would in all probability explain phenomena at present but imperfectly understood. If an organized body imbedded in a rock of chemical origin is found to be of the same composition as the stratum in which it oc-

* Edinburgh New Philosophical Journal, vols. xxiv. p. 361; xxviii. p. 155; xxx. pp. 137–310; xxxii. p. 338.

curs, the explanation is difficult; but when a plant is found in a rock of mechanical formation, and completely changed into that rock, the difficulty is increased; and, indeed, in our present state of knowledge, concerning the causes which effect the fossilization of organic bodies, it is, perhaps, inexplicable. In other instances, however, the fossilized trunks which are found in the sandstone, are of a composition entirely different from the sandstone, and are changed, though more or less perfect in internal structure, into a stony mass, all the characters of which indicate that its solution has been entirely chemical. In the generality of cases, there has been a conversion into imperfect limestone, which is highly impregnated with carbonaceous matter; while in others, there has been a change into a mass chiefly of a siliceous nature. In all, the ligneous structure exhibits numerous marks of derangement; it is twisted, compressed, and otherwise variously altered. In their animal relics, the strata of the Lothians exhibit considerable variety, and have lately afforded in their *ichthyolitic* remains much valuable knowledge. Like limestones having the same geognostical position in other districts, those of the Lothians are distinguished by the same characteristic fossils; they abound in *Producti*, and contain *Orthoceratites*, *Nautilites*, *Euomphali*, and various species of *Corallines*, of which there are in some places, as at Wardlaw in Linlithgowshire, and on the coast near Aberlady, considerable beds entirely formed, one species either constituting the whole bed, or two entering into its composition. In the circumstance of the shells being almost entirely confined to the limestone, there is an indication, that its formation is due to them, and their being preserved always entire, and not affording any marks of subjection to attrition, prove that they lived and died in the places where they are found: their absence, however, in the sandstone, can never be considered at variance with the mine-

ral proofs, which are so convincing, that both the limestones and sandstones have been formed under the same general circumstances. Concerning the remains of fishes which occur in the carboniferous limestones nothing need be said, as all that is known about them at present is contained in the great work of Agassiz ; the result of whose examination is, that they exhibit no features which in any way justify the opinion, which was so hastily formed concerning them, that they belong to genera inhabiting bodies of fresh water.

In the Lothians, as in other countries, the examination of the position of strata affords data for drawing conclusions concerning the age of the mountain-chain which forms a part of them. The period at which a mountain-chain has been upraised, is fixed between the completion of the deposition of its newest upraised strata, and the commencement of the formation of those which are resting unconformably. That this mode of determining the ages of mountains, is at once natural and free from leading the observer into error, is evident, by considering those laws which regulate the deposition of sedimentary matters. Conclusive, however, though this mode of ascertaining the age of mountain-chains may at first sight appear, still it is by no means safe in every case to consider that their upraisure is contemporaneous with the production of the unhorizontal position of certain strata, which form the low country on either side of them. Under fitting circumstances, strata may be deposited at all angles under 40 degrees; and when the cause which produced the deposition of the strata at such angles becomes progressively, as we depart from the axis of the chain, more fitted for their deposition at smaller angles, the difficulty of fixing the age of the group becomes greater, and recourse must be had to other phenomena exhibited by the rocks of the chain. If such be the arrangement, the fact of the angles nearer the central

part of the chain, decreasing as the ratio of the distance from the axis increases, might lead us to infer, that the violence of the upraising agents decreased from the central part of the chain to the exterior.

By what means then, since in these circumstances the age of mountain chains cannot, with certainty, be ascertained, are we to fix the date of their upraisure? To this question there appears to be a satisfactory answer. If, after having examined a wide extent of country, a series of strata, inclined at angles at which they might have been deposited, is found reposing upon another, which is in the greatest possible confusion, being vertical and contorted, there is almost as little reason to believe that the inclined position of the former, has in any way been influenced by causes operating on the upraisure and flexure of the latter, as there would be if they were horizontally arranged. When the examination of a mountain-chain, however, shews formations anticlinally tilted up, and no one more conspicuous for its alterations than another, the only conclusion to be arrived at is, that all have been upraised at one and the same time. On examining the Lammermuir range, for the purpose of determining the age of the chain, the result to which we arrive is, that the much disturbed rocks of the transition class have been upraised prior to the deposition of the slightly inclined secondary formations. In every natural or artificial section, where the transition rocks occur, they are either inclined at high angles, or are vertical and contorted in the most fantastic manner. The secondary formations, which form the low land, and which in many places occur in contact with them, are, however, never so disturbed; but, on the contrary, are elevated at angles consistent with the supposition that they are in their unaltered state. It is

probable, then, that the elevation of the range took place after the deposition of the transition rocks, but before that of any of the members of the secondary series. On the coast of Berwickshire, at Danskin, and at the farm of Newlands, this arrangement is conspicuous. At Woodcot, in the neighbourhood of Fala, the red sandstone is almost in a horizontal position, though, within a very short distance, in a glen running down from the hill of Pockbie, the greywacke is arranged in vertical and highly inclined positions. At Kidlaw, a village near Newton Hall, the mountain limestone approaches very near to the almost vertical greywacke of the Lammermuirs; but here there is the same tendency to a horizontal position; it is inclined at a small angle, and could not have been altered by any force acting upon the greywacke. At Dean Mill, near Fala, the same appearances present themselves; the undisturbed red sandstone approaching the transition rocks. On the coast of Berwickshire, between Lin Head, and Red Heugh, there is a series of most satisfactory junctions of the red sandstone with the greywacke; all of which allow us only to infer, that these secondary formations have been deposited on the previously upturned transition rocks. The junctional appearances exhibited in East Lothian are interesting in the history of Geological Science. From examining them, Hutton, Hall, and Playfair formed those opinions which are now invariably held in regard to such phenomena.

As we have before stated, a very coarse conglomerate in general rests on the greywacke strata. In its position, this conglomerate is precisely similar to that which conglomerate deposits in general hold, and its formation is perfectly well explained, by the aqueous disturbances which would accompany the violent and certainly sudden upraisures of the old stratified rocks on which it

rests. Causes of no greater intensity than those now in action, appear, though continued through as long a series of ages as the most confirmed Huttonian could desire, perfectly inadequate to produce such effects; but, on the contrary, in the fact of mountain chains being invariably more or less flanked with conglomerates, formed of the component rocks of these chains, and constituting mountain masses, and extensive tracts of country, there is reason to believe, that the actions at present existing, whether aqueous or igneous, though similar in nature, in their magnitude differ completely from those which existed in the primeval ages of the world. All the phenomena exhibited by the rocky masses of the globe, if viewed without any desire to explain them by a favourite theory, testify, that existing causes become progressively less adequate to explain geological appearances, as we examine from the newest to the oldest known formations.

The first locality which we have to notice as exhibiting a junction of the transition rocks with the sandstone, is in the bed of the Heriot Water, a stream which runs past the old tower of Colbrandspath. The transition rocks are inclined at great angles, and at the point where the junction is visible, they dip S. S.E. at 40°; and on these the slightly inclined sandstone conglomerate rests. (Plate I., Fig. 1.) A little to the south of the Pease Burn, the greywacke and red sandstone may, in the sea-cliffs, often be found in immediate connection, the former, dipping to the N.E. at 20°, and resting on the contorted, and in some instances vertical transition rocks, which range E. N.E. and W. S.W. (Plate I., Fig. 2. and Plate II., Fig. 1.)

At Red Heugh there is a most interesting display of the several relations of the two classes of rocks. On looking down from the cliffs, the junctional phenomena are exhibited

in the most satisfactory manner. The action of the sea has partially abraded the conglomerate and sandstone, exposing the inferior rocks of greywacke, which are either vertical, or inclined to the S. and S. W. at great angles, while the red sandstone rests upon them, and dips to the N. E. at about 15° or 20°. (Plate II., Fig. 2.) Throughout all those parts of Berwickshire, where we have opportunities of examining the relations of these formations to each other, the arrangement is identical with that of the Lothians. In Mid-Lothian, strata of white sandstone, with its associated limestones, form all that part of the country which skirts the base of the transition range of the Moorfoot and Huntlycot hills; but their position indicates as little alteration from the upraisure of the mountains, as the red sandstone series does in East Lothian. In the Gladhouse water, the sandstone is almost horizontal, and continues so to the very base of the highly inclined greywacke strata. There are, however, no sections, as in East Lothian, where the two series are found in immediate contact.

Before finishing this part of the subject, we may notice a statement which Mr Milne, in his paper descriptive of the Geology of Berwickshire, has made in regard to these red sandstone and greywacke strata. This observer states, that, in some instances, both classes of rocks have been, at one and the same time, disturbed by faults. No one of these cited examples will, however, if strictly examined, be found to exhibit appearances which allow us to form this opinion. True it is that the red sandstone varies often in its height within short spaces: thus it may surmount a high sea cliff of vertical greywacke, and also form the rocks at the sea level, but in these instances there is every reason to believe that the intermediary portions have been removed by ab-

rading agents. Every thing connected with the relations of the two rocks testifies, that the red sandstone has been quietly deposited on a most irregular surface, one presenting numerous asperities and corresponding depressions.

Having noticed the relations of the different stratified masses to each other, and their mineralogical characters, we shall next, in the same way, describe those unstratified or ignigenous formations, which are so generally associated with them. The rocks of this great natural family may be divided under two heads, the Felspathic and the Augitic.

FELSPATHIC ROCKS, INCLUDING PORPHYRY AND CLINKSTONE.

Of this class of unstratified rocks it may be affirmed, that, as a mass, it may be considered as composed entirely of felspar in different states of crystallization, and associated with various structures. Other minerals sometimes enter into its composition, but these, if viewed on the large scale, are to be considered only as of occasional occurrence. The states in which the felspar presents itself, are all those between that of a compact and an earthy mode of arrangement, and when these exhibit a determinately aggregated structure, they are porphyritic, amygdaloidal, or both. Of the structures which cannot be shewn in hand specimens, but are on a more or less colossal scale, the tabular concretionary mode of disposition is the only one exhibited by the felspar series of the Lothians, and of this in the Bass and Traprain Law there are fine examples. These tabular concretions, if examined in their relations to each other, never present appearances which can in any way justify the confusion of the tabular with the stratified structure. In the tabular structure, there is no perfect uniformity of direction, but within a limited extent the concretions dip to all points, passing into an amorphous rock ;

the lines which bound them also, never contain any matter differing from the tabular masses. In the stratified structure there is nothing precisely similar to this, and little that is analogous. True stratified masses preserve a general line of direction through a great extent, and if this is changed or obliterated, it may be referred to the action of disturbing agents. The lines of stratification are also generally produced, by the rock becoming less compact in its structure, or by the presence of a minute layer of argillaceous matter; the bounding lines of tabular concretions are, however, only lines of division. Of the felspar class there are three rocks, which may be considered as the most marked individuals of this series.

Compact Felspar, which is one of these, occurs of various shades of white, red, and grey, and by acquiring crystals of felspar, it becomes Compact Felspar Porphyry. This rock occurs in great abundance in the different felspar districts, and forms hills both in the Garleton and Pentland ranges. In size, the imbedded crystals of felspar vary from the smallest size to near an inch, and are sometimes accompanied with particles of quartz and scales of mica. Claystone, which is another member of this extensive class, is of the same general colours as compact felspar; in some instances, the various shades of colour producing a veined or mottled aspect; and as compact felspar, it occurs porphyritic. Of this rock the Lothians afford many examples; it is met with abundantly both in the Pentland and Garleton Hills. The only other rock which presents characters sufficiently well defined to justify its being considered as a marked variety of felspar, is Clinkstone. This rock occurs of various shades of bluish, yellowish, and greenish grey, and is often highly impregnated with iron; the presence of which causes it to assume various modes of marking. It has frequent-

ly a foliated structure and a glimmering lustre; very generally there is associated with clinkstone an approximation to a schistose arrangement. In this case, however, the same appearances which indicate that the causes of the tabular form are in no respect similar to those which produced the stratified, evince that the internal structure of clinkstone differs completely from that of rocks which have not resulted from a state of fusion; it is the consequence of a species of crystallization probably superinduced during the consolidation of the rock. Clinkstone also occurs porphyritic.

AUGITIC ROCKS, OR TRAP ROCKS.

The Trap or Augitic Rocks, which form the next great division of the unstratified or plutonic masses, are, it may be generally stated, composed of the two simple minerals—Augite and Felspar—all the varieties of the series being produced by differences, either in the state of their crystallization, or relative proportions. Though, in a mineralogical point of view, the members of the trap series frequently differ widely from each other, still the frequent transitions of the one into the other, are at once sufficiently indicative that the formation of all has been the effect of the same general causes, differences of structure or composition having been produced by slight diversities in attending circumstances. As in the felspathic series, so in the trap family, there are a few rocks which have the same general characters, and which may be considered as rocks which, by passing into each other, form all the varieties of this family. Of all the compounds of Augite and Felspar which occur in the Lothians, forming rock masses, Greenstone appears to be the most generally distributed. Its component minerals vary in size and colour, change in colour, however, being produced generally by the aspect

of the felspar; this, however, is far from universal, for the ferruginous matter which colours much of the greenstone of East Lothian, is equably distributed throughout the augite and felspar. In size, the components of the greenstone vary from that minuteness which causes the rock to become basaltic, to the large granular, when it becomes Syenitic Greenstone. Besides appearing as syenitic and compact, greenstone occurs under several other aspects. Not unfrequently it assumes the porphyritic structure, the basis being a very minute and small granular compound of augite and felspar; while the crystals which produce the structure are of compact, glassy, or common felspar. By containing minerals, which fill or line cavities, greenstone becomes amygdaloidal; this structure appears, however, generally to attend those greenstones which are not highly crystallized, but whose components approach to an earthy state. When structure on the great scale is observable in the greenstone of the Lothians, it is of two kinds, the globular and columnar. Of the former there are many examples, and the globular concretions vary in diameter from one or two inches to several feet. The perfect columnar mode of arrangement is of less frequent occurrence, for, though there is, in many places, a disposition to be columnar, there are but few points where this arrangement is perfect; when, however, the columns are well formed, they vary in length, thickness, number of their sides, and position.

Basalt, which is another conspicuous member of the trap series, forms considerable masses in the Lothians; it is generally of a grey or black colour; and, as in greenstone, mere ocular inspection is sufficient to prove that it is a fine aggregate of crystalline masses of Augite and Felspar. Olivine abounds in some basalts, forming minute grains; and magnetic iron ore is also very generally

distributed through it. The occurrence of magnetic iron-ore in basalt, forms a well-marked character of this rock, while the very general distribution of iron-pyrites through greenstone, appears to characterize it. By assuming crystals of basaltic hornblende and glassy felspar, the basalts of some districts frequently acquire an almost porphyritic structure. Though the vitreous state is that in which felspar most generally occurs in basalt, still in others common felspar appears. At Garry Point, in East Lothian, where a finely columnar basalt occurs, the contained crystals are of common felspar. Amygdaloidal cavities abound in some basalts in such quantities, that the rock assumes the perfect amygdaloidal structure. The basalt of the Lothians is very generally associated with the columnar arrangement, and, as in greenstone, the columns vary in position and number of their sides. The hill of Arthur's Seat, thelimestone quarry of the Hill-house, in Linlithgowshire, and other points, exhibit beautiful groups of these columns.

Considered as a group, the augitic rocks of the Lothians are remarkable, when compared with some of the other great formations of the same class which occur in Scotland, in the circumstance of the zeolitic minerals occurring very rarely in them, and then only in comparatively small quantities. Intimately connected with the unstratified rocks of the Lothians, Trap-tufa occurs; it is composed of rounded and angular masses of limestone, sandstone, slate, and trap, inclosed in a basis of trap, in different states of compactness. In size, the imbedded masses vary from the smallest magnitude to many yards. It never contains fragments of any rock which occurs *in situ* at a great distance; but, on the contrary, all are in the more immediate neighbourhood of the tufaceous deposit. Much of the country round North

Berwick is composed of trap-tufa, the masses being formed of previously existing stratified and unstratified rocks imbedded in a green wacke. At Dunbar a trap-tufa occurs, differing from the former in the circumstance of its being highly impregnated with oxide of iron, which imparts to it a bright brick-red colour. In structure, if it were not for its mineral characters, trap-tufa frequently could not be distinguished from true Neptunian formations, inasmuch as it is distinctly stratified, and also assumes a slaty arrangement. In its mode of connexion with the stratified masses, trap-tufa exhibits characters perfectly distinct from those which attend either the greenstones or basalts. It never forms veins crossing strata, and consequently can never, like them, be found as masses alternating in the same way with strata, for these alternations are in every instance only veins, which, instead of crossing the strata at angles, have been injected between them from a central point of eruption, and from a column of more or less fluid igneous matter, which, to find egress, must have broken through the strata at an angle.

The comparison of the modern volcanic tufas with those which are associated with the various trap-rocks, affords one of the many proofs that the origin of both is the same, modifying circumstances producing those differences which cause both classes of rocks to be naturally separated. In the volcanic tufa, there is the same stratified structure as occurs in that of the trap family, and the series of alternations of volcanic tufa with volcanic basalts and lavas is analogous to that of the trap-tufas with basalt, porphyry, and greenstone. The circumstance of the tufas having a stratified arrangement, and never occurring in the form of veins, intimates that the manner of their formation was intimately connected with the action of water,—that their

origin was *Neptunio-Plutonic.* If we suppose the existence of a sea sufficiently deep to allow of the eruption of igneous matter, without their assuming a vesicular structure, and that, by the decomposition of older trap rocks, there was produced a series of more or less regular strata, accidents may be found fitted for the formation of the trap-tufas and their alternations with basaltic and greenstone masses. As the comparatively modern tufas of Ætna are traversed by veins of basaltic lava, so the more ancient tufa of the carboniferous epoch is traversed by greenstone and basalt,—the posterior formation of which is evinced by their producing changes, more or less similar to those which they effect upon rocks of aqueous formation.

The structure of the trap-rocks is never vesicular, and all their relations to associated masses are such as indicate that their formation and the changes which they have produced, were effected under a compression sufficient for a perfect crystallization of the rocks from a fluid state. Through all the districts in which they occur, there is, in the arrangements of the trap-rocks, nothing partaking of that aspect which characterizes the volcanic cone—no hills formed of consolidated igneous matters arranged concentrically. There are, however, many analogous appearances; for the marks of fracture, upraisure, and all the indications of altered states of the Neptunian formations, become gradually less apparent as the strata recede from the masses which are to be considered as the disturbing agents. In regard to the question, Whether have the unstratified rocks of the Lothians been the product of one eruption, or have they been sent from below at different periods? no very satisfactory answer can be given, the want of sections exposing their mode of connection, rendering this impracticable. From the circumstance of finding, however, in a few

localities ignigenous masses, traversed by veins of the same nature, it may be at once affirmed that two eruptions of trap are indicated; but this seems to be the full extent of our knowledge. If our opinion in regard to the elevation of the greywacke systems of the Lammermuir and Moorfoot hills be correct, it is rendered highly probable that the unstratified rocks associated with these transition formations have been erupted before the deposition of the carboniferous group, or the protrusion of the Plutonic rocks associated with them ; and that their upburst, perhaps, in some respects, may have been the cause of the upraisure of the previously undisturbed greywacke and transition slates. Though this may have been the case, however, it does not follow that the actions of the igneous rocks associated with the secondary strata, were confined to them : on the contrary, they may have sent erupted masses into the older rocks ; so that, though amongst the one series of strata, rocks of a formation posterior to them, perhaps, only occur ; in the transition series two classes of Plutonic rocks, each of different relative ages, may be found.

We have now arrived at a part of the subject which is replete with interest. We are to describe those changes which igneous matters, erupted in former ages of the world, have effected on the rocks through which they issued, and between and over which they have flowed. When we consider that we now live in a land where the shock of the earthquake, and the impetuosity and desolation attending a lava stream, are neither felt nor dreaded, it is highly interesting to find, by geological examination, that the country in which we dwell with such repose was, at one time, ravaged by subterraneous action,—that its strata have been traversed by streams of liquid mineral matters,—that it has had its "phasis" of disturbance.

In contemplating these interesting relations of rocks, the mind cannot but be led to consider the great age of the world; for such eruptions took place long before the creation of man, and, in all probability, long before that of those animals which stand high in the scale of being. He who is ignorant of Geology, and of the splendid results at which, by the study of the mineral and fossil bodies of our globe, we arrive, considers the days of creation which are enumerated in the Mosaic record, as indicating the time which elapsed from the period when God first called the world out of nothing, to that when, his work being completed, he shewed the greatness of his power by calling Man into being. But he who is acquainted with the legible characters engraven on the rocks of our continents, and the various proofs which allow us to believe that Omnipotence willed that, to bring the world to a state fitted for Man, it should, before his appearance, exist for a long series of ages, can, with retrospective soul, look to the existence of beings which enjoyed life, long before the creation of his species; he can contemplate the state of the world when the higher animals existed not, and watch the hand of Deity in the progressive act of creation. Happily for science, the days have gone by when geological speculation was trammelled by the too literal interpretation of the first chapter of Genesis. The layman who dares to discover that the world was not created in six of our days, now fears not the brand of atheism, nor is in danger of being considered one who doubts the divine origin of the Scriptures, by any but those for whose opinion he need little care. The churchman, skilled in the original of the Pentateuch, tells him that there is no overstretching of the language, though an undefined period of years be considered as having elapsed between "The beginning," in which "God created the heaven and the earth," and the

commencement of the first day of creation. Some, poisoned by infidelity, and voluntarily blinded to a sense of the unphilosophical nature of arguments which they considered conclusive, have, that they might not see in this science indubitable proofs of Deity, held it up to scorn; but we are not aware that any have enlisted under the banners of scepticism from finding that, after properly studying Nature, it appeared at variance with Revelation, or that "He who made the world, and revealed its date to Moses, was mistaken of its age."

Before entering into a minute detail of the various changes exhibited in different localities, which the stratified rocks have undergone, by being in connexion with the unstratified, we shall notice the characters which rocks of both classes when in contact are found to exhibit in a greater or less degree. When in contact with Neptunian formations, all the unstratified rocks of the Lothians exhibit more or less a change of structure. If the rock is granular, when at a distance from the stratified; when in contact with it, it is found small granular or compact, and apparently homogeneous throughout. If, when at a distance from the stratified rock, the unstratified rock is compact, as it approaches the former it becomes still more dense. Greenstone passes into basalt, and compact felspar into one still more compact. It is probable that the causes of all these changes are to be found in differences in the rate of cooling, a cause which, no doubt, has been productive of much of that endless variety which is observable in the Trap series. That the planes of contact of the igneous rock with that of Neptunian origin were the very places where such changes would be produced, is to be supposed, if we recollect that, before the appearance of these igneous rocks, they had been undisturbed, and all undergoing from various actions a pro-

cess of consolidation. Besides these appearances being observable in igneous rocks, when in contact with such depositions, they are also conspicuous in some of those plutonic masses which traverse others of the same origin. In this situation, however, such appearances cannot always be expected; the igneous mass, which traverses one of a more ancient formation, may have been sent up before the previously erupted mass had cooled down, and this is rendered the more likely, when we remember, that if rocks are bad conductors of heat, when not far from the surface, they must be much more so, when deeply seated in the globe's crust. In addition to these changes in structure, there is another which appears to be referable to the same cause: very generally the traps associated with the coal strata become, as they approach the strata, gradually more and more felspathic, till at last they pass into a rock of compact felspar or claystone. In some localities associated with the strata which contain beds of trap, making such transitions, there are similarly disposed masses of the claystone felspar. In the former case the transition may be supposed to have been effected by the more rapid cooling, and in the latter the refrigeration may have been too quick to allow of the existence of the mass as Greenstone. Some strata, when in contact with these associated unstratified rocks, exhibit characters which, if the origin of the two classes of rocks were not admitted to be perfectly distinct, might easily lead the observer to consider both of contemporaneous origin. Such appearances are, however, perfectly reconcilable with the igneous formation of trap-rocks, and it would rather be a matter of astonishment, if, in some cases, they were not to be observed. By the very long continued action of heat, it might be expected that both rocks would undergo a commixture the one with the other, and that in certain places,

the junction would be so complete that there would be no line of distinct separation exhibited by the two masses in contact. Such are the changes which plutonic rocks are found to undergo when in contact with those of aqueous origin. Neptunian Rocks are variously affected by those of ignigenous formation, and very few instances can be adduced, where the structure is not in some degree changed : it may only be slightly altered ; but on minute examination changes are more or less apparent.

Of the three chief rocks, Sandstone, Shale, and Limestone, the various alternations of which form the secondary series of the Lothians, the states of change are innumerable. When the sandstone, whether it be white or red, is in contact with rocks of the trap series, it either acquires the characters of hornstone, jasper, or granular quartz-rock ; and, of course, between all these extremes, there are many different stages of alteration. The changes which are produced upon the various shales are also of great variety ; all are altered in a greater or less degree, the extreme of the alteration being observable in those cases where the shale assumes the characters of flinty-slate or Lydian stone. In the case of the indurated shales, it very generally happens, that although the hardness, fracture, and other external mineral characters are changed, there still exist the remains of a schistose arrangement, and when layers of the shale are of various colours, the rock assumes much of the appearance of the Striped Siberian Jasper. The characters which the limestone assumes, when in contact with the unstratified rocks, are in some places of the most interesting description ; it is however, to be remarked, that this rock is less frequently than any other member of the stratified series in connection with such masses ; when, however, there is a change, it is similar to that exhibited in other districts, the limestone

loses its compact for a granular structure, and its grey colour for one more or less white, these marks of alteration becoming gradually less conspicuous as the distance from the igneous mass increases. The various individuals which comprise the trap series, evince, by two modes of position, a formation posterior to that of the Neptunian strata, as well as to those older igneous masses with which they may happen to be connected. The first is that of the *vein* or *dyke*; the second is that of the *overlying* mass. In the vein, a body of trap of varying magnitude crosses the strata at an angle, or, originating in a mass which does, obtrudes itself between the strata parallel to their direction. In the Lothians the greater number of veins traverse the strata in this conformable manner, and the reason of this may in all probability be found in the fact of the planes of stratification being those which would afford the greatest facility of separation. Trap, in the overlying position, forms the most of the great trap deposits of the Lothians; when it occurs as veinous masses it is seen in its progress through the strata; but when as overlying it is to be considered as more or less in the position which it assumed when, after rising through the previously formed rocks, it flowed over their surface. The changes in position which the various stratified rocks exhibit are very great; and all are exactly such as might be conceived to attend the violent expulsion of a more or less fluid body from the interior. Fragments of the disturbed rocks are enveloped in the erupted mass, and vary in size from a few inches to many yards. Contortion, a striking position of strata, and one which is most indicative of their having been subjected to violent action, is in the three Lothians frequently well exhibited. In considering in detail the relations of the unstratified rocks of the Lothians to the stratified, we shall not endeavour to follow any

natural arrangement, but, on the contrary, will describe separately the geology of the counties of Edinburgh, Haddington, and Linlithgow.

Mid-Lothian, like the other counties, contains both classes of unstratified rocks, viz. the augitic and felspathic. The former constitutes various hills, while in the Pentlands the latter rises into mountain masses of greater or less height. The principal trap formations of Mid-Lothian occur within a circuit of nine miles round Edinburgh. Immediately to the east of the city the hills of Salisbury Crags and Arthur's Seat rise to the heights of 550 and 822 feet above the level of the Firth of Forth. The splendid geological appearances which these hills exhibit render an examination of them interesting in the highest degree, and few points can be mentioned which, within the same compass, present so many beautiful and instructive illustrations of the Plutonic origin of trap rocks. Salisbury Crags and St Leonard's Hill, which may almost be considered as constituting one hill, are each formed of a mass of trap, surmounting and rising through the slates and sandstone of the coal-formation. The igneous portions of these hills appear to have been produced by the intrusion of masses of trap, parallel to the strata, and forming lateral expansions from dykes which cross these at angles. Both the classes of rock which form these eminences dip to the east at an angle of about 30°. The trap rock of St Leonard's Hill is a slightly porphyritic greenstone; but, as it approaches the sandstone on which it rests, it changes its mineralogical characters and passes into a red greenstone of a more compact structure, or into a brownish red ferruginous claystone-felspar: it contains small imbedded masses of calcareous spar, and is also traversed by veins of the same mineral, which are frequently associated with radiated red hæmatite. Immediate-

ly below the trap lies the sandstone, which, in the vicinity of the greenstone, becomes quartzose, and also exhibits in several places various undulations. In one place there is a fine display of one of those veins, which are to be considered as forming the points of eruption. It is about 4 feet in breadth, and is vertical. (Pl. III. Fig. 1.) From this vein a lateral expansion takes its origin, running into the strata parallel to their direction ; at its origin it is about 2 feet broad, and after running for 10 feet a slightly tortuous course, it gradually thins out. On the principal vein arriving at the surface of the sandstone it flows over it, and forms the overlying trap-rock of St Leonard's Hill, and near this point the trap appears to have sunk down, and filled a hollow in the previously formed sandstone. This mass of trap is at its greatest breadth 4½ feet wide, and is almost of a circular form. At its upper extremity the mass which connects it with the overlaying trap is 1½ feet broad, and at its lower extremity there issues from it a small vein 5 inches long and 2 broad. This ridge continues to run southwards for about half a mile, and then appears to unite with the southern extremity of the trap of Salisbury Crags, and at its termination the porphyritic greenstone affords a very beautiful example of the columnar arrangement. The columns vary in length, thickness, number of their sides, and position ; those of the upper portion of the mass being inclined at a great angle, while those of the lower part are horizontal. Veins of compact and crystallized prehnite very generally occur between the sides of the columns, and in thickness these vary from half an inch to 3 inches.

The ridge of Salisbury Crags rises immediately above St Leonard's Hill, from which it is separated by a deep valley. Quarrying operations, and the making of the Radical Walk which runs along the base of the mural precipice

of this hill, have exposed in the clearest manner the various connexions of the trap with the stratified rocks. At its southern extremity both rocks, the greenstone and sandstone, dip to the N. E. by E., in the more central parts of the hill E., and at the northern end S. E. by E. and E. S. E. At the southern extremity of the ridge there is a fine example of the entanglement of masses of sandstone in the greenstone; these are changed in some places into granular quartz and in others into hornstone, the masses are several feet in length, but do not exceed a few inches in breadth. (Pl. III. Fig. 2.) The greenstone, as it does through a considerable portion of the hill, here rests upon an arenaceous limestone of a brownish-red colour, a portion of which is broken off and bent upwards amongst the greenstone. (Pl. III. Fig. 3.) On proceeding along the road in a northerly direction another mass of sandstone, but on a much larger scale, is enveloped in the greenstone: it is of a square form, and is traversed by veins of Compact Greenstone. At this point the sandstone and arenaceous limestone are contorted in various ways; and fractured in many places. (Pl. IV.) From the great disturbance manifested here, and also from the absence of that sandstone which is found under the trap, it is likely that this point has been one of the openings through which the greenstone matters flowed, and that through this fissure the mass of sandstone has been floated upwards. For a considerable way the sandstone, which is here of a red colour, is indurated, and in some places almost assumes the character of jasper, this induration decreasing as we examine at a greater distance from the indurating cause. By still advancing to the north, near a narrow pass in the greenstone called the Cat Nick, (Pl. V. Fig. 1.), where there is a shift in the sandstone, a vein of greenstone about four feet wide traverses both the sandstone

and greenstone of the Crags (Pl. VI. Fig. 2,), it must consequently be the product of an eruption posterior to that of the Crags. It runs in an uninterrupted course through the various rocks, and alters the sandstone both in position and mineral structure. As it approaches the greenstone which it traverses, this greenstone passes gradually into a more compact variety, an appearance which is not of difficult explanation, if we consider that, when in a fluid state, this vein was in contact with previously consolidated rocks.

After leaving this point, there is a beautiful display of the stratified rocks of the hill underlying the trap. These strata are various alternations of argillaceous sandstone, a brick-red calcareous clay-ironstone, and variously tinted slate-clays, all of which are arranged in perfect parallelism. These occur for a considerable way, till at last they are cut off by a great vertical vein of greenstone. It does not traverse as the other the overlying greenstone, but appears to have been one of the openings through which the protrusion of the trap has been effected. It is about twenty yards broad, and, when next the several rocks, produces alterations, and assumes at its planes of contact a compact structure. Near the northern extremity of the Crags, a vein of a highly felspathic uncrystalline greenstone issues from the principal greenstone mass, and traverses the sandstone parallel to its direction. It is about twenty feet long, and at its origin two feet broad. At the northern extremity of the hill, the greenstone sinks rapidly below the plain at the back of the Palace of Holyrood, and is covered by an assemblage of strata similar to those on which it lies. (Plate VI. Fig. 1.) These strata, lying upon the greenstone, occur more or less interruptedly throughout the whole extent of the hill, and the same changes which the greenstone effects upon the sandstone strata at the foot of the trap escarpment, are

in the upper portions conspicuous. Besides the changes which the stratified rocks exhibit from the agency of the trap, the greenstone also evinces alterations as it approaches the strata on which it rests and which surmount it: it gradually acquires a compact structure, either passing into an almost perfect basalt, or into a very compact ferruginous felspathic greenstone. From the circumstance of finding the characters of both rocks the same, whether at the top or bottom of the greenstone mass, it is evident that the sandstone and slate which lie above the greenstone, have not been deposited upon it; but have been separated from the strata which lie below the greenstone, by the subsequent intrusion of the trap-rock.

The greenstone of Salisbury Crags is in general fine granular, the felspar occurring of various shades of white, and of brick and flesh red. Sometimes, though rarely, Natrolite is associated with it, appearing to form masses not of subsequent infiltration, but of an origin contemporaneous with the rock; and very generally the compact greenstone of Salisbury Crags is traversed by numerous contemporaneous veins of greenstone. These veins vary in the compactness of their structure, sometimes being more perfectly crystallized than the containing rock, and at other times almost homogeneous throughout. They run a tortuous course through the greenstone, and are frequently of great length, while the breadth is very inconsiderable,—perhaps not exceeding two or three inches. In structure, the greenstone of Salisbury Crags exhibits nothing remarkable; it in many places has a tendency to the columnar arrangement, and very frequently assumes a globular mode of distribution, the globular concretions varying in size. In the rocks of Salisbury Crags several simple minerals are to be met with. Calcareous spar occurs most frequently, forming either veins or imbedded masses, and is occasionally

associated with radiated hæmatite. Quartz occurs in drusy cavities, being either common or amethystine, and is crystallized in the usual six-sided pyramid. Prehnite, of various shades of yellow and green, occurs in the same position, and is arranged in botryoidal or imperfectly crystallized masses. Cubicite or Analcime, is also generally associated with it. A datholitic mineral (as mentioned by Professor Jameson), to which the name of Humboldite has been given, was also at one time found in the same situation. Iron-pyrites is very generally distributed through the greenstone, and on decomposition causes the rock to assume a brownish-yellow colour. Sulphate of barytes and agaric mineral occur associated with the sandstone ; the former constituting minute veins, while the latter encrusts its exposed surface.

Separated from Salisbury Crags, by the valley of the Hunters' Bog, the hill of Arthur's Seat rises.* Taken as a whole, it appears to rest upon Salisbury Crags, and is, therefore, consequently of newer formation. The various details connected with it are perhaps not so satisfactory as those of the former ; they are, however, in many respects interesting. At the eastern extremity of the Hunter's Bog, sandstone occurs lying under a mass of porphyritic greenstone, and both dip to the S. E. at 20°. This sandstone may be traced, for a considerable way, lying under the porphyry, in which numerous masses of the sandstone occur imbedded. One of these masses is seventy feet long by two in breadth ; several of a smaller size also occur completely enveloped in the trap, one of which is visible for about twenty-five feet. (Plate VI. Fig. 2.) When in contact with the ig-

* The first published account of the geognosy of this hill and of Salisbury Crags appeared in Professor Jameson's Mineralogy of Dumfriesshire ; the description here given is nearly that which the Professor now delivers to his pupils during his geological excursions.

neous rock, the sandstone acquires all the characters of granular quartz and hornstone, and frequently assumes a green colour from containing a portion of the augite, which enters into the composition of the greenstone. Resting upon the greenstone is an alternating series of tufa and basalt. The tufa varies in its composition; it is either formed of variously sized fragments of previously existing rocks, as greenstone, sandstone, shale, and limestone, or is a fine aggregate of red ferruginous trap sand. In the tufa, a little to the south of Sampson's Ribs, a mass of red sandstone is imbedded ; a portion of which is visible for about eight feet, and has a breadth of four. It is much changed, some portions acquiring all the characters of jasper. Though the relations of this tufa to the series of trap and sandstone, which we have just mentioned, are not very evident, still it is highly probable that it is of newer formation, and that it has been protruded through them.

The summit of the hill is entirely formed of a greyish-black compact basalt, containing in some places large crystals of basaltic hornblende. On examining that portion of the hill which forms one side of the Hunter's Bog, this basalt is found to traverse the tufa in the form of a great vein, and to produce, at its planes of junction, changes similar to those exhibited by aqueous formations, when in the same situations. Near the summit of the hill, and from the western side of the large vein, a smaller one takes its origin, and traverses the tufa which it indurates. About half way down the hill, the basalt divides into two distinct veins, being separated from each other by the tufa. (Plate VII. Fig. 1.) The basalt of these veins is arranged in irregular columns. Owing to the thick covering of debris, the basalt of this part of Arthur's Seat cannot be traced to the base of the hill ; it is, however, probable that if it could be so examined, it would be found to rise directly through it, and also

the sandstones and greenstones of Salisbury Crags. (Plate VII. Fig. 2.) Imbedded in the tufa on the east side of the principal basaltic vein, a mass of white sandstone occurs; it is not, however, much altered in structure. Forming the highest point of that part of the hill which rises above the village of Duddingston, another basalt is to be observed; it is arranged in perfect columns, which vary in the number of their sides. The composition of this basalt differs from that which forms the summit, in being less compact, and containing large crystals of Labradorite Felspar, Basaltic Hornblende, and numerous disseminated masses of Olivine. Imbedded in the trap which forms the southern acclivity, there occur several masses of calcareous sandstone of many yards extent; they are completely changed in character, some portions becoming a conchoidal hornstone, while others pass into chalcedonic quartz.

At the northern extremity of Duddingston Loch, there is a mass of greenstone, identical in mineralogical characters with that of Salisbury Crags, and upon it reposes a series of sandstone and slate strata, presenting all the characters of induration. On examining the points of contact of these rocks, masses of the sandstone may be found partially enveloped in the greenstone, and compressed into the form of a vein; similar appearances are also to be observed in Salisbury Crags. On the side of the road which runs through the ravine of Windy Gowl, fragments of mountain limestone crop out, but their relations to the Plutonic rock cannot be made out. Concerning the relations of the trap of Arthur's Seat to the sandstone of Duddingston, it may be mentioned, that the want of sections prevents us from acquiring information in regard to its intimate connections with the igneous rocks; as, however, at Niddry Mill, a distance of two miles, the coal strata are found inclining

against it 50°, and as the same arrangement is to be observed at Joppa, a village near Portobello, it is evident that the disturbing influences of Arthur's Seat have extended over a considerable area. In the rocks of Arthur's Seat several minerals occur. Calcareous spar abounds, both forming veins and lining cavities; quartz occurs, either common or amethystine, and is sometimes found penetrated with spiculæ of titanium. Jasper is to be met with in several places; a vein of it occurs near the summit of the hill traversing the basalt, and another is met with in a similar position below the old chapel of St Anthony. All of these veins appear to have been produced by infiltration from above; while chalcedony is frequently to be observed as nodules imbedded in the basalt.

To the north of Salisbury Crags, in the hill of the Calton,* there is another example of igneous rocks associated with the coal formation; the form of this hill approaches to the round backed shape, and it rises to the height of 365 feet. At the new High School, forming the eminence of the Miller's Knowe, a greenstone occurs of a compact earthy structure. This greenstone is, throughout its whole extent, traversed by contemporaneous veins, which are frequently so abundant, as in numerous places almost to exceed in quantity the traversed rock. The minerals which form these veins are calcareous spar and quartz, small crystals of which associated with amethyst line the walls of minute drusy cavities. On the northern side of the hill, and also at the summit, a similar greenstone occurs, differing however in this, that it wants the contemporaneous veins. The struc-

* The first geognostical account of the Calton Hill, with a section of its structure, was given by Dr Boué in his "Essai Geologique sur l'Ecosse," from the demonstrations and lectures of Professor Jameson. The account here given is from the same source.

ture of this greenstone in some places approaches to a globular mode of arrangement, which is rendered very conspicuous by red hæmatite, forming a minute layer between the concretions ; it is traversed also by a vein of compact greenstone about six feet in breadth. Porphyry forms the principal mass of the hill, having a base in general of a bluish-grey claystone, while in others it assumes the characters of an earthy greenstone, containing crystals of basaltic hornblende and flesh-red felspar. In many places the porphyritic structure is associated with the amygdaloidal, thus forming an amygdaloidal porphyry ; the cavities in general contain only calcareous spar ; but flesh-red cubicite has been found in some places in the same position. Trap-tufa occurs in the Calton Hill associated with the porphyry, and at the back of the new High School it forms considerable beds ; the components of this tufa are in general in a state of minute division, and are principally composed of an indurated wacke. In regard to the relations of the ignigenous mass of the Calton Hill to the stratified rocks, it may be stated that it appears to have been protruded through them, in a direction more or less parallel to that of the strata. During the excavating operations which were carried on for the foundation of the Waterloo Bridge, sandstone strata were found underlying the trap of the hill, and dipping to the east at a considerable angle. Resting upon the trap, and also dipping east at angles, which decrease as the distance from the upraising agent increases, is that series of sandstone, conglomerate, and shale strata, which commences at the west end of Regent Terrace and terminates at the sea. At the stairs which lead up from the Waterloo Bridge to the hill, several strata of a red trap-tufa are found completely imbedded in the porphyry ; they dip like the sandstone upon which the Regent Terrace is built, to the east

at 20° and sink completely below the trap, near the new High School. Immediately below the old Observatory, and on the road which leads round Dugald Stewart's monument, strata of trap-tufa are again found cropping out, being included between the porphyry which overlies the masses of trap-tufa we have mentioned, and underlying those Neptunian deposits which form the western acclivity of the hill. The tufaceous strata may be traced more or less interruptedly till they disappear under the porphyry of Nelson's monument. The changes which the masses of trap-tufa exhibit when in contact with the porphyry are very great, inasmuch as they are intensely indurated. The porphyry also acquires, when next the tufa, an aspect different from that which it exhibits when at a distance from it; it becomes very compact, and frequently passes into compact felspar. On examining the points of contact of these two rocks, there is frequently exhibited an almost gradual transition of the one into the other, so that it requires considerable attention in some instances to discover where one rock terminates and where the other begins. All these appearances may, however, be easily explained, if we remember that as both rocks were in all probability once in a fluid and highly heated state, there may have been in some places a complete intermixture of the one with the other. Several simple minerals occur in the Calton Hill; jasper traverses the porphyry in minute veins; sulphate of barytes occurs in the same manner, and also masses of native copper. In the porphyry immediately below the old Observatory, veins of calcareous spar are found; and associated with the calcareous spar, glance-coal is to be met with, forming imbedded masses of various sizes. The situation of this mineral is highly interesting, and when the vegetable origin of coal is admitted, its mineralogical characters and relations to the associated

rock are only to be explained by referring them to altering agents of great power, agents of which the effects are visible more or less in almost every stratified rock of any extent. In intensely heated igneous matters rising through beds of coal under a great compressing power, circumstances may be found adequate to produce an alteration from the more evident vegetable product to this highly crystalline mineral.

Many greenstones in the Lothians (Bathgate, Uphall) contain coaly matter so disseminated through them, that it is only by the bituminous odour which they give out when struck that its presence can be recognised; this case is similar, and may be explained in the same way. The glance-coal of the Calton Hill is interesting, as it is connected with some views relative to the origin of veins. Veins of calcareous spar are in many instances well explained by an infiltration from above; here, however, such an origin is rendered doubtful from the fact of such a mineral as glance-coal occurring in them; and we appear to have a more probable explanation of some, as those of this locality, if we consider them as being produced by changes altering enveloped masses of limestone and coal. This explanation, however, rests principally on the supposition that glance-coal is of a vegetable nature. About a mile to the east of Edinburgh, at Lochend, greenstone occurs overlying strata of sandstone, and dipping to the east. Imbedded in this greenstone, there are numerous fragments of slate-clay, all of which are completely changed in mineralogical character: veins of calcareous spar traverse the greenstone, in which occur minute disseminated masses of sulphuret of lead. Near Restalrig, a village about half a mile to the east of Lochend, two beds of greenstone occur in the sandstone strata, both of these also dipping to the east. The greenstone of Restalrig is in general fine granular, and sometimes passes into

claystone. The sandstone, when in connection with the greenstone, is much indurated, and contains grains of iron-pyrites distributed through it. (Plate VII. Fig. 3.) In Broughton Street, which runs across the northern acclivity upon which the city of Edinburgh is built, trap again occurs associated with sandstone.

As the greenstone has been well exposed by quarrying operations, its various modes of connexion with the strata have been disclosed, and the result of all these observations is, that it has been protruded through the strata in some places parallel to their direction, and in others has crossed them at various angles. From the upper surface of this dyke of greenstone another takes its origin, running through the sandstone to the distance of three feet and a half; at its point of contact with the principal mass, its breadth is about one foot, and thins out gradually as it recedes from it. The sandstone on approaching the greenstone becomes indurated, while the greenstone acquires a compact structure, and is traversed in several places by veins of amethyst, common quartz, and calcareous spar. Besides these veins others have been observed in the neighbourhood of Edinburgh, but all are now completely covered. In Lothian Street one of these veins occurs associated with the strata, dipping to the east; and at the Custom-House in Albany Street and Leith Walk, there were at one time interesting exposures of trap-rocks and of the phenomena attending their relations to the various sandstones and shales.*

In the bed of the Water of Leith three other trap-dykes occur, the first of these veins, on proceeding up the stream, is to be observed a short way above Stockbridge; one of its

* In the first volume of the Edinburgh Philosophical Journal these trap-rocks are all minutely described by Professor Jameson.

ends only is visible, the mean breadth being about three feet and a half; it is vertical, and indurates the sandstone strata which dip to the N. W. at 12°. At St George's mineral well a vein of compact greenstone crosses the strata of sandstone and bituminous shale. In its progress through the strata it entangles portions of the shale, which become completely indurated, and from the minute veins which shoot from out the central mass into the stratified rocks, the high state of fluidity in which the greenstone has been erupted is apparent. (Pl. VIII. Fig. 1 and 2.) On the north bank of the river a thin stratum of clay-ironstone is shifted for about a foot, and the vein of greenstone entangles a wedge-shaped mass of bituminous shale. Like the other veins which we have mentioned, this greenstone, as it approaches the strata, passes into a yellowish-white claystone, of which the small veins which arise from the chief mass are entirely composed, —a fact at once shewing that the causes allowing the formation of the felspar have only existed in those portions of the trap which were in contact with the traversed rock, or in those which were of small size (Pl. VIII. Sec. 3.) Above the village of Bell's Mills another vein of greenstone is to be found dipping with the strata to the N. by W. It is about twelve feet in thickness, and approaches to the syenitic character; the slate which rests upon it is slightly indurated, and when in contact with it the greenstone of the vein becomes compact. On the coast extending from Newhaven to Queensferry, there is a fine section of the various rocks of the coal-formation, and these, from their relations to igneous masses, present several interesting appearances.

About half a mile to the west of Newhaven there is a distinct example of the mantle-shaped mode of stratification; it is on a small scale, and a central point may be found, from which the strata dip to all points of the compass.

The rocks which form this assemblage of strata are slate-clay, bituminous shale, clay-ironstone, and sandstone. On proceeding in the direction of Cramond, they dip to the S.E. at 25°, against the mantle-shaped stratification, and in several places the sandstone and shale are invaded by masses of compact felspar, of yellow and grey colours; but in consequence of their great disintegration, the exact relations of the rocks to each other are not seen. The sandstone and shale when in contact with the felspar are changed both in mineral character and disposition; the sandstone becoming quartzose, and the slate approaching in some places to Lydian-stone. Farther to the west the strata contain four beds of trap; one of these is entirely composed of felspar, a rock into which the others, which are of greenstone, pass, as they approach the stratified series. As usual, induration is conspicuous, and in one part a breccia is formed at the planes of contact, being composed of variously sized fragments of slate and felspar. Iron-pyrites is abundantly distributed through both the felspar and greenstone.* On following the shore, no other rocks are observable till within a short distance of Cramond, where on the beach there are three alternations of sandstone and greenstone, all of which dip to the N.W. at 20°; when in contact the sandstone becomes indurated, and the greenstone passes into compact felspar. On the western side of the river Almond which enters the sea here, another bed of greenstone occurs: it dips to the north-west, and is succeeded by strata of sandstone

* The beautiful display of Plutonian and Neptunian rocks on this part of the coast was, after its relations had been pointed out by Professor Jameson, visited by Von Buch, Boué, Mohs, Brochant, Beaumont, and many other geological chiefs. There the rival theorists discussed their geological systems. Unfortunately for the geologist, these rocks have been lately nearly entirely removed, in preparing for the new harbour in that quarter.

and shale, which continue as far as Long Green, where they are associated with a great body of greenstone, which appears to hold the same relations to the strata as the others. From this to Hound Point in Linlithgowshire, there are no interesting phenomena exhibited by any of the rocks; there, however, two veins of greenstone occur, running parallel with the strata, which dip to the west at 26°. These veins in their relations to the stratified rocks, afford exhibitions at once of the violence of their eruptions and of their changing influences, and few points in the Lothians exhibit in a more marked manner the various and interesting effects of trap rocks on stratified masses. The lowest of the two dykes which are at this point associated with the stratified deposits, rests upon sandstone, while the uppermost reposes upon slate-clay. The trap, as it approaches the sandstone, passes into claystone felspar, and when in contact with the slate becomes a very compact greenstone. (Pl. IX.) The greenstone of these veins is of the common description, and in some places, like several other greenstones associated with the coal strata, emits, on fracturing, a strong bituminous smell. The sandstone on which the lowest trap vein reposes, becomes completely changed as it approaches the greenstone, passing either into granular quartz or hornstone, while a portion of it is partially imbedded in the greenstone, the fissure produced by its separation from the other parts of the stratum having been filled up by the trap. About four feet above the junction of the trap with the sandstone on which it rests, and entirely included in it, a mass of sandstone may be observed; it is visible for about twenty-four feet, and thins gradually out, from a breadth of six inches to that of a mere thread. The slate-clay, which overlies the uppermost bed of greenstone, is in its position not remarkably altered; the line of junction is undulating, and in several places it is slightly

bent up amongst the superincumbent trap. In its mineral characters, the slate-clay exhibits marks of great alteration, and, from being a soft slate, becomes changed into a rock having little of a schistose structure, and so compact as to afford an uneven conchoidal fracture. From this to the Queensferry, there is no other junction of the trap and sandstone visible; to the west of the Queensferry, however, there are, on the shore, one or two dykes of trap associated with a tufa, the components of which are angular and on a small scale.

In the centre of the city of Edinburgh, the Castle Rock rises to the height of 445 feet, forming an eminence which, with the exception of its eastern side, presents on all quarters a perfect mural ascent. The rock of the Castle is composed, throughout its whole extent, of a basaltic clinkstone of a greyish-black colour, which is in general arranged in more or less perfect tabular concretions, and contains minute veins of calcareous spar, sulphate of barytes, prehnite, and Wollastonite. The forming of the New West Approach has displayed, in the clearest manner, the relations of the Plutonic rock of the Castle to a series of sandstone and shale which dips to the east at about 12°, and forms a gentle descent to the Palace of Holyrood. In their position the strata exhibit much disorder, being shifted and variously waved; and all, when in contact with the trap, become indurated, the sandstone passing into a quartzose variety, and the shale assuming a more compact structure. Near the gate of the Castle, several masses of the sandstone may be observed completely enveloped in the trap, all of which exhibit intense induration. Concerning the more immediate relations of the Castle Rock to the strata which occur on its western side, little can be ascertained, from the almost entire absence of openings, either natural or artificial; it may be stated,

however, that all dip to the N. W. Near Bread Street, the sandstone is crossed vertically by a greenstone dyke about six feet broad.

Immediately to the west of the city, the hill of Corstorphin rises with its wooded front, presenting a beautifully undulating surface. This hill is formed by a mass of greenstone reposing upon strata of sandstone, sandstone-flag, bituminous shale, and clay-ironstone, which dip to the N.W. at about 25°; from the encumbered state of the surface, however, no opportunity is afforded for examining any junctional appearances. The greenstone of Corstorphin is syenitic, and in several places is found to contain minute scales of pinchbeck-brown mica, and iron-pyrites, while prehnite, calcareous spar, amethyst, and common quartz are to be observed in drusy cavities.

On examining the position of the several rocks entering into the composition of the hills of Arthur's Seat, Salisbury Crags, and the Calton, it will be found that all present a uniform inclination to the W. or N. W.; and that a similar arrangement exists in the strata forming the bed of the Firth of Forth, is evinced in the island of Inchkeith.

On proceeding along the coast of Fife, the strata which at Pettycur and Kinghorn have an easterly dip, gradually assume, as we approach Aberdour, a more northerly inclination, till at last they sink completely to the north; and that this position is also held by those in the adjacent parts of the Firth, is indicated from an examination of the island of Inchcolm. After leaving the strata with the northerly dip, and advancing westward, the exposed rocks acquire progressively a westerly inclination. On the opposite coast of Linlithgowshire, the same arrangement is visible near Queensferry, and in the series of sandstone, shale, and greenstone which occurs between the river Almond and Newhaven.

The rocks around Edinburgh, and in the adjoining parts of Fifeshire, thus appear to exhibit a certain tendency to a concentric disposition. When, however, the whole district is examined, there is far from being visible that symmetrical aspect which characterizes a locality where the various mineral masses, whether aqueous or igneous, have been tilted up around an axis; but, on the contrary, the numerous instances which occur of strata, within the area of this somewhat mantle-shaped stratification, dipping to points in accordance with the supposition that an anticlinal elevating force had operated, render it probable that the appearances indicative of such an action are merely accidental. The Castle rock is a point from which many of the rocks dip, but if it had exerted an influence over so great a space, the sandstone which in many places, as at the Grange and Burntsfield, has a northerly dip, ought to plunge to the south, while many other strata, dipping to N. W., as those of Colinton, Slateford, and Craig-Lockhart, ought to sink to the S. W.

Concerning the mode by which these Plutonic and Neptunian rocks have assumed their present position, it may be difficult to conjecture; it must, however, either have been contemporaneous with the formation of the former class of rocks, or subsequent to that of both. If it is affirmed that the arrangement which the Plutonic rocks of this district exhibits is original, it may be no easy matter to explain how trap could be erupted, so as to overhang valleys without flowing into them; but, still, there certainly appears little reason to believe that the causes which have made the trap-rocks in the neighbourhood of Edinburgh to assume their existing appearances, have been others than those which arranged the alternations of trap-rock which constitute, in many districts, mountain masses. When such beds are inclined, they have

as good a right to be considered as elevated after their formation and consolidation, as the greenstone of Salisbury Crags or Corstorphin; and their vertical fronts have an aspect as like the effect of fracture as these. If all the trap rocks which exhibit a vertical front had acquired this form by being subjected to fractures, hardly one Plutonic rock in the Lothians would be exempted—all would be considered as having been elevated after their eruption and consolidation. The Dalmahoy Hills, the Bathgate Hills, Blackford Hill, and the principal trap-rocks of Haddingtonshire must, then, all be imagined to have been disturbed by igneous actions different from those which effected their protrusion; for they present perpendicular faces, and are frequently inclined at high angles.

As an instance of the pseudo-fractured appearance, we may mention Binny Craig in West-Lothian. Here there is the same gentle acclivity on one side of the hill, and mural face on the other, as is so well seen in Salisbury Crags; and there is, in short, an appearance as like fracture; but the circumstance of its resting upon horizontal strata is a sufficient proof that it could not have been elevated after its consolidation, for any upraising agent operating on it, must also have acted on the sandstone and shale. When we endeavour to shew, however, from such facts, that these trap-rocks have not been tilted up after their eruption amongst the strata, but that the inclined position is contemporaneous with their formation, it is not to be understood that we imply the same concerning the period when the Neptunian deposits were raised; for, on the contrary, these evince that they were elevated by actions subsequent to their deposition and solidification, and referable to the trap-rocks with which they are connected. The one set of rocks may be in an unaltered state, as far as their being moved

en masse after their eruption is concerned, but the appearances visible in the position of the latter, prove that they are not.

Protruded, as the trap-rocks undubitably were, under great superincumbent pressure, arising either from the presence of an immense body of water or rock, it is evident that they were not in a situation which could allow such a perfect motion of the particles on each other, as exists in a stream of fluid rocky matter, erupted only under the pressure of the atmosphere; and such a great compressing force might allow the ejected igneous matters to be piled up, one above the other, in that more or less bedded arrangement, which characterizes a trap-hill. The structure of the trap-rocks also appears favourable for their having mural precipices; for in beds which have a tendency to a prismatic mode of aggregation, and are composed of concretions arranged at right angles to the plane of the bed, there appears to exist a disposition, which of all others is best fitted for producing, in length of time, a cliff with a vertical front. Immediately after the formation and consolidation of a trap-rock erupted under the pressure of the ocean, it would begin to be subjected to the destroying action of water; and if raised above the ocean, and forming dry land, would be subjected to both the mechanical and chemical decomposing influences of air and water. By whatever agents, however, the decomposition of the mass was effected, it would proceed chiefly in the direction of the vertical concretions, so that whether the rock presented a mural front originally or not, it would, when acted on by the various agents productive of decay, assume one in a greater or less degree. By this uniform mode of disintegration going on through a long series of geological epochs, the original aspect of a trap country might be modified to such a great extent, that there might exist hardly any similarity between its former appear-

ance and its present outline; what then formed one mountain, may now be broken down into several, and the once perfect continuity of a bed of basalt or greenstone over one mountain, may now only be inferred by finding it forming mountain caps to portions of that mountain.*

In addition to the different points which we have described, where the relations of the various rocks to each other are observable, there are others; but few of these exhibit any thing remarkable. In the bed of the river Almond, at the Aqueduct Bridge, the slate and sandstone are associated with a greenstone, which forms, for a considerable length, the entire bed of the river; it is surmounted by an assemblage of shale strata, and in all probability forms a great vein which runs parallel with their direction. On the north side of the bridge these strata are found under a second bed of trap, which can be traced for several hundred yards: the slates, when in contact with the greenstone, are slightly indurated, and the trap as it approaches them, becomes gradually more compact. A short way up the river a vein of trap about four feet broad traverses the sandstone, and near this another is to be seen running parallel with the strata, which dip at about 30°, pursuing a determined course for many yards; it cannot be traced throughout its whole extent, but may be examined in the bed of the river, and also in several parts of the cliffs. Near Almondell the strata present, within a very short space, several examples of undulation, and are traversed by a vein of greenstone, having a thickness of three feet. In the limestone quarries of East Calder there are several interesting phenomena attending the relation of the limestone to the greenstone, which is of

* In the island of Rum there are several good examples of mountains being formed by the decomposition of one. The large granular augitic greenstone ridges of Haleval are only continuations of Aisgobhall, though now both of these mountains are separated by a deep glen.

the usual description, and in some places assumes the globularly concretionary structure. In the first quarry to the east of East Calder, the mountain limestone dips S. E. at 20°, under a mass of greenstone, which in the second quarry is found in immediate contact with it. In the quarry where the junction is exposed, the limestone abutts against the greenstone at a small angle, dipping E. S.E. ; a position which, at the eastern extremity of this opening, is completely reversed, as the strata sink to the W. S.W. at 15°. The limestone, which at a distance from the greenstone is of a bluish or yellowish-grey colour, becomes, on approaching it, white and beautifully crystalline, acquiring much of the aspect of primitive marble. No exact line of boundary can be drawn between the greenstone and the limestone ; on the contrary, both rocks are so intimately blended, that this locality might, if the true nature of them was not known to be distinct, be considered as exhibiting appearances only to be explained by awarding a synchronous and similar origin to both. The greenstone may be observed in all stages between a mass distinctly imbedded, to one in which it is so perfectly diffused through the limestone, as to impart to it a dark green colour : in accordance with the received igneous formation of trap, such an appearance may be explained, by supposing that circumstances caused such a perfect fluidity of both rocks, that the intermixture of the one with the other was the consequence. Like all the other trap-rocks, this greenstone, in the neighbourhood of the strata, becomes compact, and, as is often the case with trap in contact with limestone, assumes much of the serpentinous character.

Immediately to the south of East Calder, there is a considerable district of trap, which rises at its eastern extremity into the two marked eminences of the Dalmahoy Crags ; it runs E. and W., forming the hilly range of

Kirknewton and Lawhead, and appears to terminate at the Linhouse water near Longhaugh Mill. The hills of Auchinown, Morton, and Corston, form a part of this trap range. From Longhaugh Mill to Linhouse, the bed and both sides of the stream exhibit one of those alternating groups of variously coloured shales and red sandstone, which so often occur, both on the large and small scale, associated with the white sandstone series of the Lothians. A short distance to the eastward of the stream the strata are cut off by the trap-rock, which constitute all the hills on that side. Opposite Linhouse it sends out a great dyke of grey compact basalt, which crosses the river; it cannot be traced on the western side of the stream, but, judging from the external aspect of the country, it is probable that it terminates near this point. To the south of this trap-dyke, nothing in any way interesting presents itself; but in the course of the Linhouse water, there are numerous exposures of the white sandstone and its concomitant shale strata; which form, without any visible association with Plutonic rocks, a wide extent of moor ground, bounded on the south by the red sandstone hills which constitute the western extremity of the Pentland range. The greenstone of Dalmahoy rests upon white sandstone dipping west; but as it is covered at the planes of contact, its aspect, if there changed, cannot be seen. At the western extremity of this trap range, at Longhaugh Mill, there is a very satisfactory junction of the greenstone and sandstone, both of which are much altered in mineralogical character; the strata of sandstone become vertical or exhibit various undulations, and are indurated into a granular quartz, while the greenstone with which they are in contact passes into a very compact greenstone or a felspar. At the southern extremity of Auchinown Hill, and at the farm of Harper Rig, a dyke of greenstone crosses the stream, running parallel

with the sandstone strata; and in the bed of the Gogar burn at Wester Haggs, another dyke traverses the sandstone vertically, which abutts against it on both sides. At Stoneyrig also, a similar dyke occurs; there are no junctions visible, but the strata are fractured, contorted, and inclined at high angles.

Having now described the relations of the trap-rocks which occur in the more immediate vicinity of Edinburgh to the various Neptunian strata, the present appears a convenient place to introduce a description of the islands which rise above the waters of the Firth of Forth, in as much as there are circumstances which connect them with the several rocky masses which we have just noticed. Of these islands, two only, Inchkeith and Inchcolm, contain stratified rocks, and both exhibit several interesting appearances. The strata which occur in Inchkeith consist of limestone, calcareous sandstone, slate-clay, and bituminous shale, all of which dip to the S. S.W.* The igneous rocks of this island are amygdaloid, earthy greenstone, basalt, and tufa, and at the lines of junction with the stratified rocks there are produced all those changes which so frequently occur; the slate becomes indurated, the limestone crystalline, and the sandstone quartzose. In several places, masses of the stratified rocks are carried up, and completely enveloped in the trap; these masses varying from the smallest size to the magnitude of many yards. On the eastern side of the island the columnar mode of arrangement is well displayed in the greenstone. The tufa which occurs in Inchkeith is formed by a base of earthy trap containing variously sized masses of basalt, greenstone, sand-

* Vide pp. 216, 17, 18, 19, and 220 of Dr Neill's translation of Daubuison's Memoir on Basalt, for an interesting account of the geognosy of the coast of Fyfe.

stone, and limestone; it appears to constitute the lowest rock of the island, and is in general traversed by a multiplicity of veins of calcareous spar, which is sometimes fibrous. The other minerals which are met with in the rocks of Inchkeith are common jasper, and Lydian-stone, the latter of which forms contemporaneous imbedded masses and layers in the limestone. Glassy felspar occurs in the basalt, which also contains minute masses of steatite.

A little to the west of Inchkeith, Inchcolm rises. A considerable portion of this island is composed of greenstone, exhibiting either the earthy, syenitic, or common appearance, and which, by the felspar being replaced by steatite, frequently passes into an imperfect serpentine. On the south side of the island, a variety of greenstone occurs containing numerous scales of pinchbeck-brown mica; it is traversed by a number of contemporaneous veins of greenstone, which frequently passes into steatite; this mineral occurs also in minute strings without exhibiting any such transition, and in them sometimes there may be observed threads of amianthus. On the south of the island, where a junction of the trap and the sandstone is exposed, the latter dips to the north at 52°; while the greenstone, as it approaches the sandstone, passes into a compact yellowish-white claystone, a vein of which occurs running parallel (Plate X., Fig. 1.) with the strata. With the exception of a body of sandstone, which is enveloped in the greenstone, the western half of the island is entirely composed of trap, having in some places a slightly columnar disposition. Farther up the Firth, the islands of Cramond, Carcaig, Mickrey, Mickrey Stone, and Inchgarvey occur: from being entirely formed of trap, however, these exhibit nothing interesting. The greenstone of Cramond Island and Mickrey is syenitic, the felspar being white and of a light brick-red colour. At the mouth of the Firth, a range of trap islands

runs for a considerable way round the coast of East-Lothian, of which Eyebroughy and the Bass Rock form the two extremities. The Bass Rock is composed of a very minute greenstone, in which the felspar, which is compact and of a reddish-brown colour, sometimes becomes so abundant, that the rock almost passes into a compact felspar or a clinkstone. Throughout its whole extent it exhibits more or less the tabular structure, the concretions varying both in thickness and mode of position. In several places, by the incessant action of the waves upon the rock, caves have been produced, one of which perforates it completely, and is accessible at low water.

Having noticed the relations of the several detached masses of trap to the strata, we shall now describe in the same way those clinkstones, claystones, and compact felspars, which form a considerable portion of the Pentlands. The hill of Blackford, which forms the northern termination of this range, is entirely composed of clinkstone of a dark grey colour: it contains in some places crystals of felspar, and is traversed by veins of agate. The claystones and compact felspars of the Braid Hills are of various shades of grey, yellow, and brown, and are all easily decomposed by atmospherical agents. Concerning the more minute relations of these ignigenous masses to the stratified formations, the completely covered state of the country renders it impossible to determine; by examining, however, the position of the strata in the few places where this can be done, the result is, that all are found to abutt against the unstratified rocks. In the Grange Quarry, which is situated but a short distance from the clinkstone of Blackford, strata of red sandstone dip to the N. by E. at 40°; and a coarse conglomerate, which is visible for a few yards at Liberton-brae, sinks to the E. S.E. at about 35°, exhibiting, in many

places, signs of disorder. Near the village of Burdie-house, and at Straiton Mill, the coal formation sandstone, and a bed of the mountain limestone, plunge to the S. S.E. at 40° and 35°. To the west of the Braid Hills, and separated from them by about half a mile of gently undulating country, the hill of Craig-Lockhart rises, and on its east side the red sandstone which occurs at the Grange, is to be observed dipping W. at 35°. The rock which forms the igneous portion of Craig-Lockhart, is, in some places, a well-marked greenstone, exhibiting an imperfect columnar structure; while in others it approaches to basalt, containing numerous small crystals of velvet-black basaltic hornblende, and a few large crystals of glassy-white felspar. Within the space of a few feet, this rock passes into a greenstone of an earthy aspect, which makes a transition in some parts into a claystone, and in others into a wacke. The claystone into which the greenstone passes is, in general, of a greyish colour, and contains crystals of black hornblende, the crystalline form of which may often be exposed on a favourable fracture; contemporaneous veins of felspar traverse the rock in many places. In some parts of the hill a fine greenstone is found, which contains large and well-defined crystals of felspar, and resembles, in some degree, the green porphyry of the ancients; while in other parts a trap-tufa occurs, which is always distinctly stratified. On the side of the Colinton road, the sandstone strata dip N. W. at 30°, thus abutting against the trap of Craig-Lockhart.

The Pentland Hills,* as we have already said, rise immediately to the south of the Braid Hills, forming numerous rounded and conical summits, and attaining, in some

* Vide Memoirs of the Wernerian Natural History Society, vol. 2d, for Professor Jameson's outline of the Mineralogy of the Pentland Hills; and Dr Charles Mackenzie on the compact felspar of the Pentlands in vol. i. Wernerian Memoirs.

instances, to the heights of 1876 feet and 1856 feet. Mineralogically, they may be separated into two series of hills, viz. that composed of felspathic rocks, and that formed of sandstone; the former class constitutes the eastern half of the range, while the latter occurs chiefly in the western. As in the Braid Hills, the ignigenous portion of the Pentlands is composed principally of various porphyries, claystones, and compact felspars, all of which pass into one another, and preserve in their several relations no definite mode of grouping, inasmuch as the formation of all appears to have been strictly contemporaneous. A greenish-grey clinkstone occurs in several places, and in other parts a compact felspar is to be met with, which varies in colour from flesh to brownish-red, and by assuming crystals of felspar, makes, in some places, a transition into porphyry. Claystone of various colours forms many of the Pentland hills, and exists in all stages between an easily friable rock, and one of considerable solidity; very generally, it is associated with the porphyritic structure, the felspar crystals in some instances being of considerable size. Besides this claystone exhibiting the porphyritic arrangement, it becomes frequently amygdaloidal, and contains concretionary masses of calcareous spar, amethyst, quartz, chalcedony, agate, lithomarge, and green-earth. Of the claystone of the Pentlands, one only may be noticed more particularly, in as much as its characters might easily cause its true nature to be mistaken; it forms the whole of the hill of Kirkyetton, and occurs also in the Turnhouse hill. On examining this rock at first sight, it will appear as if composed of fragments of compact felspar and claystone; but, after studying it minutely and in all its details, these fragments will be discovered to be such in appearance only. The same varieties of the compact felspar, which in some places might be easily mistaken for fragments, are found in others to

occur as veins, of an origin contemporaneous with the apparently fragmentary rock; and farther, the pseudo fragments are all found, when the true fracture of the rock is obtained, to pass gradually into the containing basis.

In the augitic series of the Lothians there are greenstones which, from containing angular masses of greenstone, imbedded in a trap basis, might in some cases be confounded with a true tufa. In many instances, however, there may be observed a gradual transition of the apparently tufaceous rock into a perfectly well characterized greenstone; a fact which at once appears to prove, that the fragmentary aspect may, in some instances, be deceptive. It is almost impossible to conceive circumstances adequate to produce the passage of a true tufa—a rock which is of an evident mechanical origin—into greenstone, which is a true aggregate of more or less perfect crystals, and has resulted from the cooling of a fused mass. It may be said, that the long action of the greenstone upon the tufa, might make the semblance of a transition. When trap-tufa, however, from a proximity to such a mass, appears to have been altered, the appearances are only of that description which, in some instances, attend the junctions of true aqueous rocks with Plutonic masses. Throughout the whole extent of the Pentland range, there are but few localities where the connexions of the igneous with the stratified rocks are well exposed. Near the extremity of the valley of Glencorse, which runs in a N. E. and S. W. direction through the Pentlands, and beside the ruins of an old chapel, sandstone occurs, dipping S. at 15° or 20°, thus resting upon the porphyry which forms the north side of the glen, and sinking under that which composes the hills on the south. As to the appearance exhibited at the junction of the sandstone with the porphyry nothing can be said: throughout its whole visible extent, however, it is changed, in some places passing into

quartz-rock, and in others becoming a conchoidal hornstone. At the western extremity of the valley, and on the south of Black Hill, a natural section exhibits numerous alternating strata, of a very fine granular brown sandstone and slate. The mineral characters of the latter are in some places similar to those of the slates associated with greywacke: if, however, its position, in regard to the rocks with which it is connected, be observed, and its aspect compared with that of slates whose place in the carboniferous group is more apparent, its geological age becomes sufficiently evident. In the course of the North Esk river, from its rise in the Dodrig to Carlops, there are many fine sections of this slate; it is found alternating with the coarse sandstone conglomerate of the Pentlands, and in some places with the sandstone of the coal series. At Habbie's How the slate, which is vertical and ranges S. W. and N. E., rests upon the compact felspar of Black Hill, and throughout its whole extent exhibits evident marks of having been at one time subjected to energetic upraising actions. Conglomerate forms the western extremity of the valley of Glencorse; it dips to the W. by S. at 15°, being thus in a position anything but conformable with the slate. As we have already stated, however, that the synchronism of deposition of these two rocks is well seen in other parts of the Pentlands, the causes of this may in all probability be referred to the upburst of the Plutonic rocks, with which both are so intimately connected. On examining the conglomerate, as exposed by the cascade of Habbie's How, it is found traversed by minute veins of a compact felspar, similar to that which is associated with the slate; it is however more compact, and thus affords another instance of that change of mineral character which the ignigenous rocks evince, when they traverse Neptunian strata in the form of veins, or come in contact with them as overlying masses.

Concerning the appearances which the conglomerate exhibits, when near these veins, it may be remarked, that they are the same as many which we have before described as attending similar rocks in similar situations; it become intensely indurated, and has a more or less perfect conchoidal surface. The felspar of Black Hill is found to contain imbedded masses of this conglomerate many yards in extent, and on its eastern side, near the farm of Craigentarrie, strata of red sandstone are found in an almost vertical position; slate the same as that of Habbie's How is also to be observed in several places intimately connected with the compact felspar.

Besides all these interesting relations of stratified to unstratified rocks, we have, in the formation of the valley which separates the hill of felspar from the conglomerate of Habbie's How, a subject of considerable interest, and an example of one of the many valleys which cannot be satisfactorily explained by referring them to the long-continued action of the streams which traverse them. In speculating upon the origin of valleys, it is necessary to examine whether these have been produced by actions aqueous or igneous, and subsequent to the formation of the rocks which they traverse, or whether they are to be considered as original depressions. In regard to the valley of Glencorse, the relations of the several rocks which we have just noticed, render it evident that it is not an original depression, but that subsequent actions, whether aqueous or igneous, have produced the existing arrangements. That this valley has been formed by the long-continued action of the insignificant stream which at present runs through it, is, as we have just remarked, highly improbable; on the contrary, however, it and all other valleys, presenting the same characters, may be satisfactorily explained by considering them as having originated in more or less limited lines of fracture.

In the three Lothians, we might cite innumerable examples of gorges and ravines, which, though traversed by streams, still, from the great disproportion which exists in their relative magnitudes, have evidently been produced by agents in no way connected with the water which flows through them. To form these valleys by water, some geologists may only demand a great lapse of time; but others, from considering their various appearances, and remembering that, if a given cause is inadequate to produce a given effect, the endless operation of that cause avails nothing, will only refer them to great and instantaneous convulsions.

The high vertical faces of the rocks, in every instance, exhibit evident proofs of fracture, and present no appearances which can reasonably be considered as produced by the long-continued action of a stream. Though alterations in the position of strata, are, in the generality of cases, to be referred to the presence of unstratified rocks, still many of the rents which we are noticing, seem, from crossing strata which are in a horizontal position, and, in many instances, far removed from igneous masses, to be referable to other Plutonic actions than those which have protruded the augitic and felspathic series. On the nature of these we have no intention to speculate at length. May they not, however, be traced to the actions which raised the countries we are noticing above the waters of an ancient ocean? As some localities where fissures appear to traverse the strata, we may mention the Heriot, Dunglass, and Pease burns, the glen of Pockbie near Soutra Hill, and numerous points in the courses of the rivers Almond, Leith, Gladhouse, and North Esk.

The slate which is seen in an upraised position at Habbie's How, is to be met with in other parts of the Pentlands: near Bevelaw House, it occurs in vertical strata, ranging

N. E. and S. W., and is traversed by two vertical dykes of greenstone, the largest of which is about twenty feet wide; but neither the greenstone nor the slate exhibit any marked signs of alteration.

Above the village of Currie, the hill of Warklaw rises through the white sandstone series, which occurs abutting against it in the bed of the Water of Leith; it is partly composed of a common greenstone, and partly of a porphyritic clinkstone, and on its south side, strata of red sandstone, in some places highly calcareous, are found reposing. On the banks of a rivulet which takes its rise at the foot of Harbour Hill and joins the Braidsburn here, the white sandstone is found dipping N. N.E., being cut through by a dyke of trap which dips N. at 80°. All the rocks are indurated, the sandstone passing almost into granular quartz, and the argillaceous shale becoming compact. The greenstone which occurs here is of the usual description, and is arranged in perfect globular concretions. On the other side of the greenstone dyke, the strata dip to the S. S.W., resting upon the red sandstone, which reclines against a rock of compact felspar. After leaving Bevelaw Quarry, and proceeding along the Pentland range, the igneous rocks are found to be replaced by the red sandstone, which constitutes, with the exception of one or two veinous masses of trap, all the remaining Mid-Lothian portion of the Pentlands. In East Cairn Hill, the sandstone rises to the height of 1802 feet, forming a well-marked table-shaped mountain, and on its south side, the strata of sandstone crop out, and dip to the north at about 25°. Concerning the immediate agents which have caused the red sandstone of this quarter to rise into mountain masses, we cannot speak with certainty, inasmuch as they are all completely concealed. In the porphyry hills of the range, however, there exist causes quite suffi-

cient for their upraisure, and the existence of these or similar rocks, below the sandstone, may easily have produced the disturbances which the position of the various slates and sandstones evinces they must have been subjected to. The sandstone-conglomerate which occurs in the bed of the Linton Water is, near the farm of Cairn Muir, traversed by a large vein of greenstone, which is in some places amygdaloidal; it cannot be traced throughout its whole extent, but it runs a course parallel with the direction of the strata, and gradually thins out. The conglomerate, at its planes of junction with the greenstone, however, exhibits no appearance of induration. (Plate X. Fig. 2.)

The only other trap-rock which occurs in the Pentlands, and deserves to be noticed, is a greenstone associated with the red sandstone of Carlops. This mass of trap forms the central part of a valley running E. and W. for nearly a mile; its sides are composed of red sandstone and conglomerate, having a position which, though not very satisfactorily displayed, appears to indicate that the strata have been tilted up anticlinally. The trap which appears to have been the agent in causing this arrangement does not form an uninterrupted ridge, but, on the contrary, has been broken up by subsequent actions, which have left only portions expressive of its former complete continuity. At the eastern extremity of this dyke of trap, the cutting of a new road has exposed a vein of earthy greenstone, which runs parallel with the strata of the white sandstone series, and can only be considered as a lateral expansion of the principal trap vein. The strata when in contact with it are not altered, and both rocks dip S. S.W. at about 35°. At the village of Carlops, the eastern extremity of this great trap-dyke is traversed by an infinity of veins composed of quartz, in the different states of hornstone,

jasper, chalcedony, and cachalong: they run a determined course; and in breadth vary from the smallest size to two feet. The fact of there being exhibited in the structure of the larger of these veins evident marks of mechanical actions, renders it probable that none are of an origin contemporaneous with the trap. Many of the veins are composed of an aggregate of fragments of white and black hornstone, cemented together by a similar basis; all these fragments are angular, and frequently they may be reunited to each other in the imagination. As to the variety of the hornstone which constitutes these fragmentary masses, or forms the base which contains them, there is no regularity observed, for in some portions of a vein the masses are of black hornstone, imbedded in a white hornstone ground, while, in other parts angular fragments of white hornstone are inclosed in a base of the black. To explain the mode in which these veins have been formed in the existing state of knowledge in regard to this subject is perhaps impossible; an infiltration from above, however, of the minerals which constitute them, is the most probable mode of their formation, while a breaking up of the previously formed veins and their reconsolidation, by a new infiltration of quartzose matters, may have effected those appearances which indicate mechanical actions.

Concerning the relations of the porphyry of the Pentlands to the strata which skirt their southern base, little can be said, inasmuch as there are no natural or artificial openings sufficiently near the junction of the two rocks. In the bed of North Esk river there is almost throughout its whole course, a fine section of the various strata of the coal formation, but in no part are they in any way connected with rocks of ignigenous origin, though that they have

been acted upon by disturbing agents, their position renders sufficiently evident.*

Having now noticed, with considerable minuteness, the various relations of the ignigenous rocks of Mid-Lothian, to the associated stratified formations, we shall in the same way describe similar phenomena which are exhibited in Haddingtonshire.† A considerable portion of this county is composed of igneous masses; they form all that part which which is included by a line, stretching from Whitberry Point to Linton and Pople: the line of trap-rock here assumes a westerly direction, running along the north back of the Tyne as far as Haddington; and, making a 'detour' by Bangly, passes near Ballencrief and Drem toll, till at last it terminates in the sea, forming Goolan Point. Though this is the most extensive body of trap which occurs in East Lothian, still there are others of a smaller size which exhibit many interesting relations. As in Mid-Lothian the augitic or trap-rocks are associated with those of the felspathic or porphyry series. Rocks of the latter class constitute the Garleton Hills, a range forming the high land which occurs above the town of Haddington, and they enter also into the composition of the eminences of North Berwick-Law and Traprain. The

* Near the town of West Linton, situated at the farther extremity of the Pentlands, felspathic rocks again appear, rising through the red sandstone. The hill of Mendic is entirely composed of a brown claystone porphyry. In its characters, the white sandstone which occurs around West Linton, exhibits some appearances differing from any of the other white sandstones of the Lothians. It contains, as an ingredient, a great abundance of yellowish-white claystone, and indeed, it is only by examining this rock in all its details that its true nature can be ascertained; for, when the lines of stratification are imperfect, and no alternations with a more characteristic sandstone visible, it might easily be mistaken for one of those claystones, which in some parts of this district rise through and occur between the sedimentary deposits.

† Vide Dr Ogilvy on the Trap-Veins of East Lothians, Wernerian Memoirs, vol. i. Also Professor Jameson on the Geognosy of the Lothians, Wernerian Memoirs, vol. ii.

mineral characters which these rocks exhibit are on a general view similar to those which occur in the former county; there are, however, some which merit a detailed description. The porphyry of the Garleton Hills has in general a basis of a largely foliated clinkstone, inclosing crystals of felspar; it passes into clinkstone, and in other parts into compact felspar; and associated with these porphyry and clinkstone rocks, there occurs at the Abbey toll of Haddington a felspar tufa, containing imbedded angular fragments of porphyry and compact felspar. Much of the country in the neighbourhood of Linton is composed of a highly felspathic greenstone, which passes in many places into claystone. The augite and felspar which form this rock are, from being highly impregnated with iron, of a brownish-red colour; it is very small granular, exhibiting in some places a tendency to a tabular arrangement; and in the quarry of Pencraik, where the felspathic greenstone is worked to a considerable extent for road material, it is traversed by numerous veins of sulphate of barytes, associated with calcareous spar and fibrous brown hæmatite.

In describing the relations of this great deposit of trap and felspar rock, to the stratified formations, we shall commence at the southern extremity, which rises above the village of Garvald, forming Whitelaw Hill. At this point the strata of red sandstone are found dipping at 10° to S.W. by S., thus abutting against the igneous rocks,—a position, however, which they are far from universally holding; for, in tracing the sandstone round the unstratified rocks, it is found in many places to sink under them, or to be inclined at a small angle. Such apparently unchanged positions of the strata may, however, easily be reconciled with the intrusive origin of trap or felspathic rocks; if it be remembered that much of this ignigenous mass may be in an overlying position, and occurring only as a great body, which,

after being erupted through the strata, has flowed over them. Near Hollandside, and on the southern acclivity of Traprain-Law, sandstone is exposed for a few yards, dipping to the S. W. at about 20°, thus resting upon the porphyry, to which a slight appearance of induration is probably to be attributed. It sinks below a porphyritic basalt, which with claystone forms one of the sides of the valley of Blakie's Haugh. The felspar porphyry of this hill is in many places arranged in very distinct tabular concretions, which vary both in magnitude and position. Of the southern part of this extensive formation of trap, the only point which exhibits in a very clear manner the protrusion of the trap, subsequent to the formation of strata, is in the limestone quarries of Sunnyside. In one of these openings, the mountain limestone, with its associated variously coloured slate-clays, dip to the north at 30°, lying under a ferruginous felspathic greenstone, which is found rising through them in the form of a dyke of about three feet in thickness; there are no appearances of induration, but the slates exhibit several undulations. (Pl. X. Fig. 3.) The effects of the trap upon the limestone cannot be observed, though that it does traverse it, the fact of crossing strata which rest upon the limestone at once proves.

At Phantassie the same limestone appears, in the immediate vicinity of trap; and tracing it eastward, it may be examined at Balgone in the neighbourhood of the ignigenous rocks. The limestone here is considerably indurated, and contains numerous small veins of calcareous spar, in which drusy cavities occur, lined with minute groups of quartz-crystals. In position, this limestone is very much altered; it is fractured and contorted, and in many places the lines of stratification are much obliterated. The position of the white sandstone of this part of East Lothian, as it is exposed in artificial openings, and in the

bed of the Tyne, is more or less horizontal, an arrangement of the strata, which, but for junctional phenomena visible at other points in this district, might lead us to imagine that they had not been acted on by ignigenous masses.

To trace the junctions of the two classes of rocks through that part of the country which extends from Haddington to the shores of the Firth of Forth, is, from the obstacles which so often mar the progress of the geologist, impossible. On examining, however, the shore which stretches from Morrison's Haven to Dunbar, numerous rock sections of the most interesting nature may be observed. The strata are traversed by intruding masses of trap, and these, it is highly probable, are connected (though the encumbered state of the surface prevents such connections from being seen,) with that great East Lothian district of trap, the boundaries of which we have just defined. On examining the northern shore of East Lothian, the first mass of trap which is observed occurs at Morrison's Haven ; it is a greenstone of the usual description, and rises directly through the sandstone, which on one side rests upon it, and on the other sinks below it ; no junctions are, however, to be found. On proceeding along the coast in the direction of Cockenzie, the various strata of sandstone and slate evince much disturbance, and preserve no general line of bearing, but, on the contrary, dip at varying angles to various points of the compass. At the harbour of Cockenzie a great mass of large granular greenstone occurs ; it rises directly through the strata which, on one side, dip to the E. S.E. at 30°, and on the other to the S. Between this and the greenstone which forms Goolan Point, other greenstones are found associated with the coal sandstones and slates ; one of these at Bogle Hill is rudely columnar, and throughout its whole visible extent runs parallel with the strata, which, when in

contact with it, become indurated, while the trap passes into a yellowish-white claystone felspar. On passing Goolan Point, strata of sandstone and mountain limestone crop out at the shore: they dip under the greenstone and exhibit many marks of a disturbed position. About two miles farther to the east many other greenstones occur, but their modes of connection with the strata are not exposed. Near Red House a basalt rises through the sandstone: it is arranged in columns of the most symmetrical character, which, in some places, are inclined at a small angle, while in others they are variously bent or completely vertical. By assuming crystals of felspar, the basalt acquires, in some places, a slightly porphyritic character. From this to Weaklaw, a point almost opposite the island of Fidra, there is nothing which deserves minute detail; strata of sandstone, with alternating limestone, are exposed on the shore, but their position is so disturbed, and they are so covered with debris, that little can be ascertained respecting them; they alternate, however, with various felspars, both compact and tufaceous. At Weaklaw the strata of the white sandstone series are replaced by the red sandstone conglomerate in a horizontal position, and exhibiting several gentle curvatures, which are probably to be referred to the presence of a body of earthy ferruginous greenstone upon which the conglomerate reposes; but in regard to induration, there is nothing very conspicuous, the conglomerate being highly compact throughout. Between this point and North Berwick several other trap dykes occur, associated with the red sandstone; none, however, are remarkable: they are all composed of greenstone, different varieties of which occur in different parts of the same vein:—thus one part of a vein may be composed of a greenstone of an earthy character, and containing oxide of iron as a colouring matter, while other

portions may consist of amygdaloid, or be rendered porphyritic by containing numerous crystals of felspar. Veins of calcareous spar, associated with quartz, traverse the greenstone, and both these minerals occur crystallized in drusy cavities. Nearly opposite the Lamb island a few minute strata of fetid limestone appear, but nothing in regard to their relations with other rocks can be ascertained. At North Berwick a mass of trap runs boldly into the sea, intruding more or less parallelly among the red sandstone strata, forming one side of the harbour. The island of Craig Leithie lies immediately opposite the trap of the harbour of North Berwick, indicating, as do all the other trap islands which skirt this coast, a continuity with the trap-rocks occurring on the shore. About a mile from North Berwick the hill of North Berwick-Law rises, with its beautifully conical form, above a comparatively level country; in its geological structure, however, it exhibits nothing interesting, and its relations to any of the stratified rocks are in no place observable. A brownish-red felspathic greenstone, associated with trap-tufa, forms the lower part of the hill, while the summit is composed of a clinkstone, which exhibits a slightly tabular arrangement; its mode of connexion, however, with the greenstone and the tufa is completely obscured. The series of strata which sinks under the trap of North Berwick Harbour, is, after being visible for a short space, covered up by a sandy beach, through which rocks of green trap-tufa are afterwards found emerging. This tufa is in many places distinctly stratified, and is composed of variously sized fragments of red sandstone, limestone, and trap, cemented together by a basis of comminuted trap. Veins of greenstone, in one or two places, traverse the tufa, and some, by effecting changes on it, produce those appearances, which

at one period were considered as indicating a precisely similar mode of formation.*

On examining the coast between Canty Bay and Sea Cliff, several detached masses of red sandstone may be observed underlying the tufaceous deposit, which, in some places, forms mural cliffs of great thickness, and presents an almost uniform horizontality of its beds. Near Scougal the green trap-tufa is succeeded by one of a brick-red colour, containing fragments of the same description as those which occur in the green. After this an extensive sandy beach covers up the subjacent rocks, and nothing can be observed till we arrive at Whitberry Point· The trap-rock which forms this headland has been described as exhibiting appearances which were considered inconsistent with a Plutonic origin, and, instead of being viewed as a protrusion through the strata, its position was thought to be more naturally explained, by precipitation from above; that it had sunk down upon the previously formed strata when they were in a soft state. If there existed no similitude between trap-rocks and productions of modern igneous formation,—if there were no changes effected on the strata by the trap of Whitberry, such a deposition from above might appear a legitimate inference; but in the present case it has been deduced from the observation of one class of facts only. (Plate X. Fig. 4.) On the northern side of the trap of Whitberry Point, which ranges E. N.E. and W. S.W., strata of red sandstone and va-

* A rock near St Andrew's, which is known by the name of the Rock and Spindle, affords a fine example of a basaltic vein traversing trap-tufa; when near the basalt, the tufa becomes indurated and the basalt more compact than when at a distance from it. Vide Memoirs of Wernerian Natural History Society, vol. ii. for a Memoir on the Mineralogy of the Neighbourhood of St Andrew's, in Fife, by Dr Fleming.

riously coloured slates dip under the trap to the E. S.E. at 20° and 25°; but on crossing the ridge of trap, the strata completely change their position, and dip under it to the N. N.W. at 45°. The appearances which the strata assume when near the trap are of the most satisfactory nature; all are indurated, the sandstone passing into granular quartz and hornstone, while the slates assume those characters which they usually exhibit, when acted upon by ignigenous rocks. The trap of Whitberry varies in different parts; it is however principally composed of a rock of very large granular greenstone, arranged in beautifully regular tabular concretions, and associated with a ferruginous basaltic greenstone, exhibiting also in many places the tabular structure. When next the stratified rocks, the Plutonic masses become more compact, losing their crystalline structure for a more or less earthy state of aggregation. Interposed between the sandstone strata and the greenstone a trap-tufa in some places occurs, consisting of a basis of red wackaceous trap, in which are imbedded angular-shaped masses of red sandstone, limestone, and slate, identical with those which are in contact with the greenstone.*

We have now described the various relations of the principal mass of the unstratified rocks of East Lothian to its attending strata, and shall now finish this part of the subject by noticing other, but less extensive, examples of ignigenous formations.

On leaving Whitberry Point, and proceeding in the direction of Dunbar, a vast extent of flat sandy beach completely hides, as far as Belhaven, all the subjacent rocks; at the confluence, however, of the Belton water and the sea,

* Dr Macknight, in the 2d volume of the Transactions of the Wernerian Natural History Society, has described this point under the name of "*Ravensheugh.*"

strata of sandstone, shale, and red calcareous ironstone, similar to those exposed at Whitberry Point, again appear, dipping S. S.E. at a small angle. At Wilkie Haugh a great mass of greenstone rises through the strata and traverses them in veins, which, in some instances, run a distinct course for several hundred yards. On examining these veins numerous masses of the various stratified rocks which they traverse are found completely enveloped, all of which are intensely indurated. Forming a mass imbedded in this greenstone, a body of trap-tufa, several yards in extent, is to be observed ; it is composed of angular fragments of sandstone, slate, trap, and felspar porphyry, which are held together by a basis of red trap. The greenstone of this point is of the usual description, but as it approaches the sandstone it becomes highly charged with iron, which causes it to assume a reddish-brown colour. Cavities lined with crystals of amethyst and quartz occur in the trap ; it is also traversed by numerous minute veins of calcareous spar, and in one place by two of sulphate of barytes, which vary from one to four inches in breadth. Proceeding along the shore in the direction of Dunbar, slightly inclined strata of sandstone, ironstone, and shale are exposed for a considerable way, lying under a deposit of a red trap-tufa of great thickness, which forms the sea-cliffs till within a short distance of the Castle. The tufa which occurs in such abundance in this part of the coast is composed of fragments of various trap-rocks, of sandstone, limestone, ironstone, and shale, all of which vary in size from the smallest magnitude to one or two feet, and are imbedded in a base of red wackaceous clay, which, in some instances, without containing the usual fragments, occurs for a considerable extent, and, throughout, exhibits a more or less stratified arrangement. The tufa is in some places traversed by veins of greenstone, but these afford no remarkable appearances.

A short distance from the coast, the hill of Knockinghair rises; it is composed of a highly ferruginous compact trap, and exhibits a structure which might at first be considered brecciated. On examination, however, this fragmentary appearance will be found to be only an instance of that original concretionary structure, which, in many instances, may with little difficulty be confounded with a rock of a true fragmentary nature. Numerous large and well defined crystals of basaltic hornblende are frequently to be found in the trap of Knockinghair.

Between the termination of the tufa, which forms the cliffs to the west of Dunbar, and the trap on which the castle is built, the shore is formed of sandstone, which dips to the E. S.E. at a small angle. At this point a mass of trap, which is known by the name of the Doo Rock, rises through the sandstone strata; it is in some places a basaltic or amygdaloidal greenstone, while in others it partakes of the tufaceous character. The strata with which this rock is in connection in some instances abutt against it, and in others sink below it. In several places great masses of the sandstone are enveloped in the trap, all of which are changed in their mineralogical characters, becoming either conchoidal hornstone or granular quartz-rock, and frequently acquiring a green colour, from an intimate commixture with the augite of the trap. At a short distance from this rock the trap of the Castle rises vertically through the strata of sandstone; the western part of this mass is composed of a red felspathose porphyritic greenstone, and, at the junction of the sandstone with the trap, and for the distance of several yards, the strata become intensely indurated, almost passing into jasper, and losing, to a considerable extent, the distinctness of the lines of stratification so apparent in other places. After rising through the sandstone the trap flows over it, and joins another mass of trap; the strata are slightly bent up by these

Plutonic rocks, and large portions are enveloped in them and indurated to a great extent. The trap deposit on which the Castle of Dunbar is built differs in different parts —in some places being composed of varieties of red basaltic greenstone, and in others of tufa; and in one place, where the sea has formed an arch, masses of indurated sandstone of many yards extent are entangled in the trap rock. Concerning the relations of the greenstone of the rock of Dunbar Castle to the tufa, we may state that, though in some places it appears of a newer formation, still a complete examination allows only the conclusion to be drawn, that the rocks of this point have been the result of igneous actions, which were not discontinued till all these masses were elaborated.*

Between this and Dunbar Harbour, sandstone strata occur arranged in the most irregular manner, dipping to various points, and in some places sinking under the trap of the Castle; they are here also broken through by another intrusive mass of greenstone, but their immediate modes of connection cannot be made out. At the harbour tufa occurs of the same description as that which we have already noticed, and is traversed by a rock which may be described as a very fine granular ferruginous felspathic greenstone, which, in some places, becomes porphyritic from containing minute crystals of felspar. The structure of this rock is beautifully prismatic, the columnar concretions being, in some instances, fifteen feet in length: they vary in the number of their sides; figures of three, five, and six sides are,

* The interesting geological phenomena which the castle rock of Dunbar exhibits can only be perfectly examined from a boat, and observers who desire to investigate this locality in detail, will find a correct guide in a map lately published by Mr J. Mason, Land-surveyor, Belhaven, and entitled "Plan of Dunbar Castle and Bay Rocks."

however, the most usual forms, and on decomposition, these columns appear to consist of globular concretions, regularly superimposed on each other. On examining this columnar rock at right angles to the axis of the prism, the globules exhibit an alternating series of layers of a very ferruginous trap, with others having a less quantity of iron disseminated through them, and separating the columns: there very generally occur veins of iron flint.

The late Dr M'Culloch, in his System of Geology, vol. i. p. 172, describes this rock as a sandstone rendered columnar by a slow refrigeration from a state of igneous fusion. In a theoretical point of view, this is an error of much importance, as it is awarding a changing power to igneous action, of greater magnitude than, in this instance, nature warrants us to do. The situation of this rock, erroneously described as columnar sandstone, is one which is the reverse of harmonizing with a metamorphosis on so gigantic a scale as exists in the altering of a stratified sandstone into one perfectly columnar. It is interposed between beds of trap-tufa, a rock which does not, in the generality of cases, appear to have been in so highly-heated a state as to change, to a great extent, the original structure of strata. In regard to its chemical composition, we may mention, that this is as incongruous with its being an altered sandstone, as are its mineralogical characters, all of which are too plain to allow it to be a subject on which two opinions can with propriety be held.* The only other trap rock which occurs on this shore appears about a mile to the south of Dunbar; it is composed of greenstone, either compact or amygdaloidal, and is many yards broad. It contains numerous veins of calca-

* A rock having the same mineral characters as that of Dunbar, but amorphous, occurs at Usan, a fishing village near Montrose. It is associated with claystone amygdaloid.

reous par, and also, though very rarely, minute imbedded masses of amianthus. The strata of red sandstone, which are exposed on the shore between Dunbar and this point, dip in general at about 20° to the E. S.E.; but as they approach this dyke of trap they gradually pass into the white sandstone series, and progressively assume higher angles, till at last there is a complete reversion of position, and they dip to N. W. at 50° reposing on the greenstone. (Pl. XI. Sec. 2.) In the interior of the county of East Lothian, there are several other points where ignigenous rocks have intruded among the sandstone strata; few of these, however, exhibit any appearances which require a detailed description. By following a mountain rivulet, which rises in the Hill of Wightman, and joins Stonecleugh Water, near Stotancleugh, five dykes of ferruginous red greenstone cross vertically the conglomerate, which is inclined to the N. E. at 10°; these veins are all parallel the one with the other, and stand up in the form of walls, the strata in which they occur having been partially removed by the action of the atmosphere. In regard to the appearances which the conglomerate puts on, when in contact with the trap, they are not of a marked nature, induration being only recognizable in the fact of small portions of the conglomerate still adhering to the sides of the trap veins. (Pl. XII. Fig. 1.) If we consider, however, the coarseness of this conglomerate, and that it is held together so imperfectly, as to be liker shingle on a sea-beach than a rock of such antiquity, the want of induration may not be wondered at. In no place can there be a more conclusive evidence that the origin of greenstone and these stratified rocks is perfectly distinct; for, in this instance, a rock, bearing on its front all the characters which might be expected to occur, in a mass at one period in a state adequate for the crystalline arrangement of its components, rises

through another, which, if it is not of as mechanical an origin as the most modern detritus, could not, if it were so, present any other suite of characters. Another point, where we have found a greenstone connected with the sandstone conglomerate, is on the side of the road, near the farm of the Brunt; there is, however, nothing in its relations different from those we have just mentioned. At Oldhamstocks also, a great dyke traverses the sandstone, appearing on both sides of the Stonecleugh burn, and also in its bed; no junctions of this rock with the sandstone are visible, and throughout its whole extent it presents only the characters of a basaltic greenstone.

Concerning the relations of the transition rocks to the unstratified masses, there are few points in the Lothians where we have noticed any thing interesting, and the comparative rarity of such rocks in this group is, in some degree, remarkable. The disturbed position of the secondary strata is, in general, referable to the presence of augitic or porphyry rocks: the numerous flexures, however, which are visible in the transition series, can, with few exceptions, be traced to visible masses of an eruptive nature. To explain this appearance is, in the existing state of our knowledge concerning the causes productive of mountain chains, a subject of no little difficulty; but it is not unlikely that the great high land of the south of Scotland has, as other chains, been elevated by actions of a more general nature (as far as the mass of the globe is concerned) than those which effect the protrusion of igneous rocks. It has been proposed to explain the marks of violence which are visible throughout mountain chains, by the influence of innumerable earthquakes acting along a given line, during a period of great duration. A geo-

logist, however, who, without any preconceived notions or blind adherence to any theory, examines the structure of such chains as the transition range of the Lammermuirs will, when he finds strata extending through immense tracts of country fractured, and exhibiting flexures of great extent, observe little which he can consider similar to the effects of modern earthquakes. In the disturbances visible in mountain chains, we can only discover proofs of energetic actions which had not been subject to innumerable interruptions, but were, on the contrary, of comparatively short duration.

Forming a considerable part of the bed of the Fassney water, and also extending for a short distance down the Whitadder, after the confluence of the two streams, an unstratified rock occurs, exhibiting rather interesting characters. It is a highly crystalline aggregate of variously sized concretions of felspar and hornblende; black mica in some places occurs, but is to be considered more as an accidental mineral than a true constituent of the rock. The felspar which enters into the composition of this rock is in general of a flesh-red colour; at other times, however, it is white or grey, and then the rock can only be considered as an ordinary greenstone. The structure of this syenitic greenstone is in general tabular, but in some places it exhibits a globular arrangement; the decomposing influence of the atmosphere removing a softer and more easily disintegrated rock, in which are imbedded concretionary masses of a more compact and lasting variety. In several places, this syenitic greenstone makes a transition into compact felspar, and at the Keelstone pool it is traversed by a broad and apparently contemporaneous vein of brownish-red felspar. Veins of sulphate of barytes, associated with the green carbonate of copper and prismatic copper-glance, occur

also in one or two places, but never of a size sufficient to be of importance in an economical point of view. Concerning the relations of this crystalline rock to the greywacke series, it is to be regretted, that the entire absence of sections at those points where the two rocks come into junction, prevents any change, either in mineralogical structure or position, from being observed; in one place only, the greywacke is found in the neighbourhood of the syenitic greenstone rock, and then, there is no greater appearance of alteration than is exhibited in other parts where no plutonic rocks are visible. It must, however, be stated that the strata abut against the ignigenous mass at about 75°, but in no instance is the syenitic rock found to alternate with the greywacke. The same covered state of this country, which renders the exact relations of these two rocks to each other impossible to be seen, causes also the topographical boundaries of both to be obscure. After minute examination, however, the crystalline rock of Fassney may be stated to be bounded by a line running along the lower part of the acclivity of Priestlaw Hill to Painshiel; it then runs along the foot of Dod Hill, to nearly opposite the old castle of Gamelshiel, when it bends with a circular direction to Mill-know; stretches along the foot of Spartleton Hill, and joins the southern line of its boundary at about half a mile to the west of Snailscleugh; and thus appears to form the lowest rock or basis of the Hills of Priestlaw, Spartleton, and Painshiel.* After the greenstone rock has disappeared in this stream, near the farm

* In Berwickshire a syenitic greenstone, similar to that of Fassney Water, forms the hill of Cockburn Law, and like it, is connected with the greywacke strata. The modes of its association here, however, are better exposed than in the Fassney, and in several places it may be found traversing the transition strata. The Syenitic Greenstone of Fassney

of Painshiel, rocks of greywacke are exposed, being arranged in more or less vertical strata. The greywacke varies in mineralogical character from a rock of which the compounds are distinct, to one homogeneous throughout; to determine the true nature of which, if all its relations were not distinctly seen, would be attended with no little difficulty. It has a very dark blackish-brown or bluish-grey colour, a conchoidal fracture, a slight translucency on the edges, and on being struck, emits a highly sonorous sound. Associated with these greywacke strata, near Bull's Leap, felspar occurs, containing a few acicular crystals of augite: it is conformable to the strata which are vertical, but its more immediate relations are not observable. Farther up the stream, and near the junction of the Kilpallet Burn with the Fassney, two dykes of felspar, in some places slightly porphyritic, cross the strata. (Pl. XII. Fig. 2.) On the eastern side of the first of these veins the strata dip to the north at about 80°, and on the western side, to the south, at the same angle. At the junction of these rocks, there are appearances the very reverse of induration, inasmuch as both the greywacke and the felspar are completely disintegrated. On advancing up the stream other two dykes present themselves, running parallel with the vertical strata; the first of these is a porphyry with a base of compact felspar, containing crystals of felspar,

Water is described, by Professor Playfair in his "Illustrations of the Huttonian Theory," as a "true granite." If, however, the term "granite" is meant to express a definite mineral aggregate, and is not applied in that vague and general manner in which it has become unfortunately fashionable to use it; the natural class to which the rock of Fassney belongs may easily be discovered. By paying little attention to the various marked characters and connexions of the true granites and syenites, the nature of many unstratified rocks has been misunderstood, and to the same inattention we may refer many of those inferences which have, in no inconsiderable degree, affected theoretical geology.

along with minute masses of quartz ; it is only visible *in situ* in the bed of the stream, but as numerous blocks are strewed over the surface of the adjacent hill, it is probable that this vein is related to the strata, both as a dyke which runs parallel to their direction, and also as an overlying mass. Near this, a rock of felspar containing crystals of augite appears, but there are no opportunities afforded for determining its relations. Felspar, both compact and porphyritic, occurs in many of the hills in this quarter, but its modes of connexion with the greywacke are in no instance ascertainable. In the hills of Redstone Rig and Newland, felspar rocks are met with, and at Kidlaw, a farm near the House of Newton, there are exposed two dykes of felspar, which traverse vertically the greywacke slate; and on proceeding up a stream, which runs from the hill of Middlemuir, the same strata are associated with a vesicular felspar, which is quarried and used for lining kilns, but nothing can be discovered in regard to the modes of its connexion with the strata. In the bed of a stream which runs past the farm of Newlands, a compact felspar is associated with the transition slate, on which horizontal strata of red sandstone conglomerate rest, a circumstance of importance, as it renders it highly probable that the eruption of the unstratified rocks connected with the greywacke has been anterior to the deposition of the secondary strata of this district. Near Fala, in a ravine which leads down from the hill of Pockbie, several veins of porphyry occur, associated with the vertical strata of greywacke. The basis of this porphyry is of a yellowish-red compact felspar, and contains numerous acicular crystals of a light green hornblende ; its associations with the strata are, however, in no instance interesting.

Concerning the relations of the unstratified rocks of West Lothian to the several strata with which they are connected,

little appears worthy of a detailed description, and as the country is covered to a great extent with peat and alluvial matter, and is traversed by comparatively few large streams, satisfactory junctions of the igneous with the aqueous rocks are of unfrequent occurrence. In regard to the relative distribution of these rocks the greatest disorder exists, small deposits of the coal series appearing in many places completely isolated and enveloped in the ignigenous formations. The position of the strata is also of the most irregular description, since in one part they are found dipping to one point, and in another are disposed in the reverse, or lying in an apparently unaltered and horizontal state; in general, however, the angle of their inclination is, with few exceptions, far from high; a circumstance which can perhaps only be explained by supposing the greater part of the augitic rocks of this district, as a series of sheets of trap overlying the surfaces of the strata and at a distance from the eruptive openings. In regard to the points which may have been those of greatest disturbance, there are no certain indications. The hills which range from Bathgate to Borrowstownness, the Riccarton Hills, and the trap deposits of Corstorphin, Craigiehall Hill, and Mons, may, however, be considered with some probability as the more immediate centres of the trap eruptions. In describing the modes of connection of the trap of West Lothian with the strata, we will notice first the Bathgate Hills, and conclude with a detail of any remarkable phenomena observable at other points.

At the most southern part of this range of trap hills near the village of Kirkton, the quarrying of the limestone which forms a considerable portion of this district, has exposed several interesting phenomena in regard to its relations to the trap rocks. The general inclination of the

limestone is to the N.W. In the old quarry of Kirkton, the surface rock is a greenstone which, in some places, partakes of the characters of basalt, and frequently evinces a tendency to the columnar arrangement; it rests in its course on different rocks in different parts of the quarry, in one part being directly superimposed on a fine slaty tufa, composed of a minute aggregation of wacke and trap sand, while in another it is in immediate connection with a thin bed of mountain-limestone which gradually wedges out at both extremities.* Below these thin strata of limestone, a thick bed of slaty green tufa occurs, resting through the whole extent of the quarry on the principal limestone stratum. (Plate XII. Fig. 3.) In regard to changes in mineral character, neither the tufa nor the limestone exhibit any thing marked; they are as compact at a distance from the greenstone, as when in immediate contact with it; they present however, numerous flexures, and in one or two places shifts have taken place in the limestone. Near the old quarry of Kirkton, and almost on the same line, another opening has been made, and there the same general arrangement is visible; the limestone, with its concomitant strata of slate-clay and ironstone, is surmounted by the same trap and green tufa, the latter of which is connected with the limestone in the most irregular manner. The mineral characters of this limestone differ in some degree from the other; it abounds in contemporaneous imbedded masses of hornstone, and alternates with strata composed of siliceous,

* To those who are inclined to consider the limestone of Kirkton as of fresh-water origin, from the statement of Dr Hibbert in the 13th volume of the Transactions of the Royal Society of Edinburgh, "that a decidedly fresh-water limestone is there exposed, which is characterized by the absence of all marine shells, coral, &c.;" we may mention, that the fact of its being so characterized is incorrect, inasmuch as we have found in it specimens of the Productus.

argillaceous, and calcareous layers, which exhibit, in regard to each other, a perfect parallelism. In position all the rocks afford evident marks of disturbance, they are waved and contorted in the most fantastic manner, these wavings varying from an extent which may be recognizable in a small specimen to an undulation of many yards. The limestone contains the usual plants of the coal series, and also fossilized wood.* On crossing the country from Kirkton, in the direction of Bathgate, the strata which are exposed in these quarries appear to be cut off by a mass of greenstone, against which, the limestone of Peter's Hill abuts, at an angle of 30°, apparently underlying a deposit of trap, which rises immediately above the town of Bathgate.

In the limestone of Peter's Hill, hornstone is abundant, forming contemporaneous masses; madrepores also abound,

* Having forwarded a specimen of the wood from this locality to Mr Nicol of Edinburgh, he very kindly offered to examine it, and after doing so, sent me the following description of its internal structure:—

"Dear Sir,—I have examined the specimen of fossil wood you discovered in the carboniferous limestone of Bathgate, and shall now give you the result.

"Externally the specimen is of a bluish-grey colour; when recently broken the fracture is greyish-black, but on being polished the bluish-grey colour returns. It is penetrated with veins of quartz and calcareous spar, and its hardness is such as to give fire, though faintly, when struck with steel. On inspecting the cross fracture, the ligneous structure, even without being polished, may be distinctly seen. When cut transversely into a thin slice the reticulated texture appears in the most perfect state of preservation, and more closely resembles that of the recent Araucaria than any other fossil I have hitherto met with. To see, however, the structure to advantage, it is necessary that the slice be moistened with water, for when dry its opacity is such as to render the structure very obscure. The longitudinal section parallel to a radius displays with great distinctness the araucarian polygonal discs arranged in single, double, triple, and quadruple rows, but, as in the cross section, to see these in perfection the slice must be penetrated with water, for when dry, even in the thinnest possible slice, the opacity is so great that scarcely a trace of them can any where be seen.—Yours, &c.

"Wm. Nicol."

and the productus is of very frequent occurrence. At Galla Braes, the limestone is penetrated by a large mass of earthy greenstone running parallel with the strata. Though the covered state of the quarry completely obscures the exact relations of these rocks; still, from the fact of the greenstone appearing only on one side of the quarry, it is probable that, if circumstances allowed a complete examination, it would be found to wedge out. From near Galla Braes to Mount Eerie, there is a very long and deep opening, exposing strata of clay, ironstone, sandstone, and limestone, dipping under a thick overlying mass of greenstone, and abutting against some trap cliffs, which occur at a few hundred yards distance. At the eastern extremity of this quarry, working operations have exposed the direct junction of the trap with the slate-clay, but there is no mark of alteration in position or structure; the slate-clay however assumes, to the distance of two feet from the trap, a yellowish-brown colour. On the side of the road leading from Mount Eerie to Bathgate, felspathose greenstone occurs intimately associated with fine granular slaty tufa, and contains imbedded masses of elastic mineral pitch. A short distance to the north of Mount Eerie, in the north and south Silver-Mine quarries, the strata of slate, ironstone, and limestone, are well exposed, but exhibit no junction with the trap rocks which cover them, and against which they abut. The limestone of these two quarries is of a dark bluish-grey colour; while that of Kirkton, Galla Braes, and Mount Eerie, is yellowish-grey, and passes into a black flint, which generally contains well preserved madrepores. Between the Silver Mine and Wardlaw, there are no openings which afford junctions of the stratified rocks with the greenstone; there, however, the trap is found connected with the limestone, both as a vein and also as an overlying

mass; when in the latter mode of position it, in every instance, rests upon slate-clay, which is indurated to a considerable extent, but concerning the appearances which the limestone exhibits when in contact with the traversing mass of trap, the encumbered state of the surface prevents any determination. The only other quarry where the stratified rocks are well exposed, as regards their relations to the trap, is at Hill-house; the strata consist of slate-clay, sandstone, and limestone, and dip N. W. under the trap at 40°. None of the Neptunian rocks, however, when in contact with the Plutonic mass, afford altered appearances. The trap which reposes upon this series of strata is a beautifully columnar basalt, and becomes in some places porphyritic, from containing crystals of glassy felspar. The columns are regularly formed, and are arranged, in general, at right angles to the plane of the bed. In the neighbourhood of Linlithgow, the limestone is quarried at several openings, but can in no place be examined at its junction with the several trap rocks, which are invariably found overlying it. At the village of Winchburgh, there is a mass of trap which, in two places, is found in immediate contact with the strata; it is in general a greenstone of the common character, but in some places becomes syenitic; and is frequently globularly arranged, the concretions varying in size. Near the bridge which crosses the Canal, two dykes of greenstone occur, traversing the strata parallelly, and dipping to the north at about 25°, being separated from each other by several layers of slate-clay, which are indurated to a considerable extent, and assume the characters of a slate which is found in a similar situation at Lochend, near Edinburgh. At the line of junction with the trap, the strata exhibit wavings and other indications of violence, and are crossed by an infinity of rents or joints at right

angles to the plane of the bed. On these dykes there reposes an extensive series of sandstone, slate, and ironstone, but there are no opportunities afforded for examining the connexions of the strata with the hanging side of the uppermost vein. (Plate XIII. Fig. 1.) The other opening where the Winchburgh trap rock is seen in contact with the sandstone, is in a field on the side of the road at Muiryhall (Plate XIII., Fig. 2.) ; it is highly satisfactory, and the quarrying operations have exposed the several relations of the rock in a manner sufficiently distinct. A mass of greenstone rises through the sandstone, and, on arriving at the surface, flows over it, forming an overlying body of variable thickness, and issuing from this mass, a minute vein runs a short course between the strata of sandstone, and decreases in thickness as the distance from the vein in which it originates increases. The characters which the several stratified rocks assume when next the unstratified, are here well displayed, but are precisely similar to those which may be remarked in almost every locality in the Lothians, where the two classes of rocks are found in contact or near connexion. The sandstone, as it approaches the greenstone, gradually assumes a compact structure, till at last it acquires such a degree of induration as to present the appearance of a granular quartz ; while the greenstone, as it approaches the sandstone, becomes felspathose. By following the Ecclesmachen burn from Niddry Castle, strata of sandstone are seen cropping out in several places, appearing to constitute the bottom of the valley, while the sides are composed of greenstones which rise into the eminences of Tar Hill, Craig, &c. At the village of Ecclesmachen, several inconsiderable strata of limestone are to be noticed in the bed of the stream, but though trap is in their immediate neighbourhood, there are no junctions exposed.

To the west of the house of East Binny, the picturesque rock of Binny Craig rises, presenting on this side a gentle acclivity, while its western side forms an almost mural front. It is connected with strata of slate clay, but exhibits no remarkable appearances. Near the inn of West Craigs several interesting phenomena were once exposed at the junction of greenstone with a bed of coal, which was completely changed into glance-coal;* at present however, the quarry where this appearance was observable is completely covered up, so that not even a specimen of the coal can be found to indicate its existence.

At Magdalenes, where the Union Canal crosses the road near Linlithgow, an earthy tufaceous greenstone occurs, containing numerous imbedded nodules of splendent glance-coal; it is frequently associated with calcareous spar, and in some instances, when the coal is less highly crystallized, a ligneous structure may be detected.

In addition to the points in Linlithgow which we have detailed, there does not appear another worthy of minute investigation.†

We shall now notice the matters which form an envelope of varying thickness to those ignigenous and aqueous mssses, the mutual relations of which we have just detailed. In

* This glance-coal was particularly examined and described to the Wernerian Society by Professor Jameson many years ago.

† The chemical composition of the rocks of the Lothians has been very partially examined; details connected with this department of science are, however, highly interesting, and when rock masses have become more generally analysed, results will, in all probability, be obtained which will bear on some of the more speculative parts of geology. The mineralogical and structural changes which the several stratified and unstratified rocks exhibit when in contact, are now investigated and generally understood, but to such junctions chemical analysis has, with few exceptions, been applied. We quote the following analysis of rocks of the coal formation from the 29th volume of the Edinburgh New Philosophical Journal. The rocks were selected by Professor Jameson, and the analysis entrusted

describing these deposits, geologists have, very generally, classed them under two heads, viz. Alluvium and Diluvium, and in this order we shall very shortly examine the several loosely aggregated masses which are met with in the Lothians.

The alluvial rocks which occur in this district may conveniently be considered as of three kinds, viz. those resulting from vegetable decomposition, and thus forming the modern analogue of coal, "*peat;*" those derived from the

by him to Dr Wm. Gregory who had them conducted under his own immediate superintendence by two of his pupils, viz. Mr John Drysdale, who analyzed Nos. 1, 2, 3, 4, and 5, and Mr J. Walker, who analyzed Nos. 6, 7, and 8.

1. Basaltic rock of Largo Law, in Fifeshire.

Silica,	45.2
Alumina,	14.4
Protoxide of Iron,	14.0
Lime,	12.7
Magnesia,	6.55
Soda,	5.22
Water,	2.4
	100.47

Edin. New Phil. Jour. xxix. p. 388.

2. Compact felspar from the Pentlands.

Silica,	73.5
Alumina, with a trace of Iron,	11.23
Carbonate of Lime,	2.5
Potash,	3.55
Soda,	3.8
Water,	4.6
	99.20

Edin. New Phil. Jour. xxix. p. 195.

3. Felspar rock, Wardie, near Newhaven.

Silica,	37.20
Alumina,	9.75
Iron,	20.00
Lime,	8.57
Magnesia,	3.78
Carbonic acid and Water,	20.80
	100.10

Edin. New Phil. Jour. xxix. p. 195.

4. Greenstone from Wardie, near Newhaven.

Silica,	44.00
Alumina,	11.4
Protoxide of Iron,	22.32
Lime,	8.8
Magnesia,	2.5
Water and Carbonic acid,	10.5
	99.52

Edin. New Phil. Jour. xxix. p. 195.

5.

decomposition of the subjacent rocks, and thus forming various kinds of *Soils* or *Earths*, and, finally, those pro-

5. Slate-clay from Wardie, Newhaven.

Silica, .	.	60.00
Alumina,	.	17.60
Oxide of Iron,		15.21
Lime, .	.	2.36
Loss by Heat,		4.41
		99.58

Edin. New Phil. Jour. xxix. p. 195.

6. Unaltered slate-clay from Lochend.

Silica,	.	58.22
Alumina,	.	17.50
Protoxide of Iron,		10.53
Lime, .	.	trace
Magnesia,	.	4.62
Soda,	.	2.02
Water,	.	6.70
		99.59

Edin. New Phil. Jour. xxix. p. 387.

7. Altered slate-clay from Lochend.

Silica, .	.	53.25
Alumina,	.	17.56
Oxide of Iron,		8.64
Lime,	.	6.62
Magnesia,	.	2.70
Soda, .	.	7.85
Water,	.	2.23
		98.85

Edin. New Phil. Jour. xxix. p. 387.

8. Altered slate-clay from Salisbury Crags.

Silica,	.	66.100
Alumina,	.	19.5
Oxide of Iron,		trace
Lime, .	.	6.4
Soda, .	.	4.45
Water and Carbonic acid,		3.3
		99.65

Edin. New Phil. Jour. xxix. p. 387.

To the above we now add the early analysis of the late Dr Kennedy of Edinburgh :—

Analysis of the "Whin" (Greenstone) of Salisbury Crags by Robert Kennedy, M.D., F.R.S., F.A.S. Edin., Trans. of the Royal Soc. of Edin, vol. v. p. 90.

Silex, .	.	96
Argil, .	.	19
Oxide of Iron,		17
Lime,	.	8
Moistures and other volcanic matters,		4
Soda about,	.	3.5
Muriatic acid about,		1
		98.5

Sp. gr. 2.802.

Analysis of the "Whin" (Porphyry) of the Calton Hill by the same, vol. v. p. 92.

Silex, .	.	50
Argil, .	.	18.50.
Oxide of Iron,		16.75.
Carbonate of Lime,		3
Moisture and other volcanic matters,		5
Soda about	.	4
Muriatic Acid about		1
		98.25

Sp. gr. 2.663,

duced by chemical actions. The peat which occurs in the Lothians exhibits nothing remarkable; its modes of position and other aspects being the same as those which characterize it in other districts. The untransported soils or earths are interesting, both in an economical and chemical point of view; and that their study is of great importance, even in a geological sense, is well exemplified in the Lothians, since in many parts it is, in a considerable degree, by reference to their characters that the nature of the subjacent rocks can be ascertained. The soil originating from the decomposition of the greywacke country has its characters; that derived from rocks of mountain limestone and sandstone has also each its peculiar and marked appearance, while that produced from the disintegration of the trap series has its own distinct aspect. Though, however, all these rock-formations produce a peculiar soil, still he who from experience has been able to form a conjecture as to the nature of the inferior rocks, by observing the soil which covers them, will find himself unable to impart the knowledge he is in possession of. Of the alluvial transported class of soils there are many varieties; all the valleys through which the rivers and streams flow being covered to a greater or less extent with rolled fragments and sands, derived from the decomposition of the rocks which they run over in their progress; those portions of the country also which form the coasts are to a greater or less extent covered by an alluvium, which is generally to be considered as resulting from the more or less direct action of the waves on those rocks which come under their influences. The banks of the Tyne, of the Esk, and of the Almond, afford deep sections of gravels, sands, and clays; and all the coasts, especially where they are level and not surrounded by mural cliffs, present wide extents of marine sands of unknown depth, portions of which, travelling by prevailing winds, encroach

on the land and form sandy soils or links. Alluvium produced by chemical agents is, in the Lothians, comparatively rare, and that which does occur is, in every instance, a deposition from water charged with calcareous matter.

On the shore of East Lothian, near Thornton Loch, there is a considerable mass of calcareous tufa and sinter, incrusting the white sandstone. Near Tantallon Castle there is another example of a similar deposition, coating the rocks of trap tufa; and, in several places throughout the Lothians, the sands and gravels which occur on the banks of the rivers and sea-beaches are more or less consolidated by calcareous and ferruginous matter. The animal and vegetable remains which are found in the alluvium belong all to existing species; bones and antlers of the stag are frequently found, and several years ago an almost perfect skeleton was discovered on Sir A. Hepburn's estate of Smeaton, in Haddingtonshire. In regard to the vegetables imbedded in alluvium, we may state that trunks of trees, many of which are of great size, are to be found in every peat moss of any extent.

Of the deposits of the second class—the diluvium—there exists in the Lothians several examples, but the study of these does not allow us to draw many inferences in regard to the circumstances which effected their distribution. In this district little extent of country can be passed without numerous rolled masses of rocks occurring, which are not found *in situ*, but in distant localities; or, if the fixed rocks from which these are derived are met with in the neighbourhood, there appear at least to be no causes in action capable of reproducing such a distribution. On the coasts of Linlithgowshire and Mid-Lothian, in the valleys of the Pentlands and on their acclivities, on the flanks of the Lammermuir and Moorfoot range, we may easily detect rolled

fragments of granite, syenite, greenstone, porphyry, mica-slate, gneiss, quartz-rock, and varieties of greywacke, which are met with only in the central districts of Scotland, while an examination of them shews, that they decrease both in magnitude and frequency of occurrence as we advance southwards, a fact indicating that the aqueous currents (for to such only can they be referred) diminished in intensity as they were removed from the more central parts of the island. Scattered around Edinburgh, numerous masses of trap-rocks are met with, which appear to be derived from no great distance.

Near Ratho, there are diluvial clays in which rolled fragments of greenstones, identical with those which occur *in situ*, in the neighbouring hills, are abundant. Superimposed on the limestone of Bathgate, and skirting the flanks of the hills, which range onward to Linlithgow, diluvial deposits of great thickness appear; none of these, however, as far as we have observed, contain masses of the primary rocks; indeed, it is probable that these clays have not been produced by the same current which distributed the numerous boulders of old rocks over the Lothians.

Of the diluvial class of clays and sands, the country around Edinburgh exhibits several interesting examples. A formation of sand and clay containing imbedded fragments of older rocks covers up the country around Newhaven and Leith, and extends as far as Joppa, in some places forming high mural cliffs. In East Lothian, a very thick deposit of diluvium may be observed, covering the rocky strata between the Dunglass and Bilsdean Burns, and consisting entirely of rolled fragments of the various rocks of the district, arranged in a more or less stratified manner: and near the Siccar Point, lofty sandstone cliffs are surmounted by a diluvial conglomerate, formed of rolled masses of the

same description, compactly held together by a basis of calcareous sinter.

In several places around the coast of the Lothians, sands, a considerable number of feet above the level of the Firth of Forth, have been found, containing shells of species at present existing, and the position of these has been explained by supposing that there has, in this district, been, within a very modern epoch, an elevation of the land. That some of these deposits of existing shells are in situations relative to the sea, which its present level and other circumstances seem inadequate to place them in, we may at once affirm; but there certainly seems to be no reason why such appearances should be referred to a rising of the land, rather than to a local recession of the sea; and if we consider the estuarial character of the firth, perhaps the latter may be most likely.

In all countries composed of several distinct rock-formations, it is invariably found, that each one exhibits on the great scale a certain range of characters;—the hills have a peculiar form, the cliffs a certain style of fracture, the valleys a particular mode of grouping with other characteristic features. In the transition or greywacke range, which forms the southern highland of this district, there is, in the outline of the mountains, an appearance perfectly distinct from that presented by any other elevated country in the Lothians. When viewed from a distance, the hills have a gently undulating contour; all are more or less round backed, and are generally covered to the summit with vegetable soil; while, in some instances, by the disintegration of the strata, they are strewed with an infinity of masses of greywacke and slate, affording a barren and uninteresting surface of light grey rocks. The valleys in the transition country are in general of limited

dimensions, and are almost universally traversed by a stream, the magnitude of which depends on the angle which the valley forms. If a stream is on the side of a mountain, it is in general narrow, and cuts through a valley which increases in breadth as it approaches the one, into which other mountain streams discharge themselves. In regard to their physiognomy, the secondary rocks of the Lothians present appearances distinct from those of the greywacke group. The red sandstone, which is the oldest member of the secondary system of the Lothians, rises, at the western extremity of the Pentlands, and in the eastern part of the Lammermuirs, into mountain masses, of a table-shaped or round-backed form, and has, with the exception of some of the porphyry hills, an elevation next to that of the transition strata. In the conglomerate districts, the valleys through which rivers flow are almost entirely destitute of soil, and present a more or less extensive deposit of the rolled blocks which enter into their composition. The country formed of the white sandstone series, when viewed generally, affords a considerable contrast to that of the red; when it is not visibly affected by the ignigenous masses, with which it is so generally connected, its surface is that of a very gently undulating line, the depressions being trivial. At the western part of the Lothian coal-series, this comparatively level position is reversed, inasmuch as the white sandstone rises there, in the hills of Leaven Seat, Woodmuir Height, and Muldrondrum, to the heights of 1164 and 1106 feet.

The two great classes of unstratified masses which occur in the Lothians, exhibit, in a marked manner, the aspect which characterises them in other districts. The hills formed of the porphyry or felspathic class, differ from the other mountainous parts of the Lothians, in the fact of the

eminences which are composed of this series approaching more or less to the conical shape; there are felspar mountains, however, having the round-backed form, but generally, it may be stated that they present an outline more or less acute. The trap series also affords those well marked characters of form, which have from their almost universal occurrence, awarded this descriptive title to the group. Large extended and more or less parallel ridges of dark-grey rock, having a face in general approaching to vertical, often perfectly or rudely columnar, and separated from each other by a slope covered with debris or vegetable soil, constitute the general aspect of a trap hill. In the trap valleys, also, there is a system of characteristic forms: they are most frequently of inconsiderable dimensions, and appear, in the generality of cases, to present no indications of any formation but one synchronous with that of the trap deposit in which they form depressions. They are almost always irregular in their levels, and not sufficiently extensive to be traversed by any bodies of water, which in size deserve to be raised to a higher rank than that of streams or rivulets, and it is from this circumstance that the lower parts of the trap valleys are frequently more or less in a marshy state.

Concerning the topographical distribution of the several formations which constitute the Lothians, the highly covered state of the country prevents us from being able to assign to each minute lines of boundary. The bounding line of the transition strata with the secondary deposits which skirt them, is somewhat irregular: it may be stated, however, that in Haddingtonshire, no rocks of this group occur to the east of a line running almost north and south through Crichness, Kist Hill, Dod, Watchlaw, and East Heartside; a little to the north of this, the line assumes, at the farm of

Pathhead, a westerly direction, and runs thus as far as Duchrie Dod, a hill near Presmennan. From the Dod hill of Duchrie, the greywacke country is then bounded by a line running N. E. and S. W. near Stoney Path, Castle Moffat, Ryestubble, and Danskin. After leaving Danskin, the boundary line assumes an east and westerly direction, passing near Quarryford Mill, Bog Hall, Cairny Haugh, and Newton Hall, when it turns to the S. W. running through Stob Shiels, Blegbie, Keith Hill, Pockbie, and Soutra Mains. In Mid-Lothian there is hardly any irregularity in the direction of the line which separates the transition from the secondary rocks; indeed, it may be said to stretch with little variation directly W. S., the hills of Cakemuir, Fala Hill, Ruther Law, Wullmuir, Turtichen, Huntly, and Mausely, forming a well defined boundary. In regard to the distribution of the secondary formations, they form, with the exception of numerous detached masses of trap rock, and the felspathic range of the Pentlands, the whole of the three Lothians, unoccupied by the transition series. In East Lothian a formation of red sandstone and variously coloured shales, forms a great extent of undulating country; this deposit, however, exhibits no exact line of boundary, as it passes always by an insensible gradation into the regular coal-formation. We may, however, affirm that by drawing a line from Cockburnspath through Thornton and Oxwellmains to Broxburn, we indicate, in a sufficiently exact manner, the district in which the transition of the one series of sandstone into the other takes place. Dunbar, the course of the Tyne from its confluence with the sea to Preston Kirk, Sunnyside, Pople, and Whitelaw Hill, may be stated as chief points, between which and the transition strata no other rocks but those of the red sandstone series occur.

The northern boundary of the red sandstone formation in East Lothian, after this, becomes more obscure, from the circumstance of a transition taking place into the white sandstone series: the line of gradation appears to run S. W. near Salton, Keith village, and Costerton, till at last in Mid-Lothian it is terminated by a very ill defined boundary, running more or less south from Crichton Dean to the base of the greywacke hills. On the sea coast, extending from Whitberry Point to Weaklaw, several minute masses of red sandstone appear, all of which are generally associated with rocks of igneous formation.

In Edinburghshire and Lanarkshire, red sandstone forms a considerable portion of the western division of the Pentland range. As in East Lothian, the northern boundary cannot be recognised, but the most natural line of distinction appears to be that, where the transition of the one formation into the other has been completed; and this line seems to run more or less in the neighbourhood of Wark Hill, Harlaw, Upper Buteland, Harper Rig, Easter Cairns, Wester Colzium, and Crosswood. The westerly part of the red sandstone may be said to be bounded by the felspar rocks of Black Hill, West Kip Hill, and Spittal Hill, while on the south it runs parallel with the new line of road from Nine Mile Burn to West Linton. Mountain limestone occurs in numerous points in the Lothians, forming bands which cross the country in different directions, and of these the most extensive is that which in Mid-Lothian skirts the base of the Moorfoot range. The most western point in Edinburghshire where this formation is exposed, is in the Hieflat quarry near Howgate; to the west of this, however, it is worked extensively at Rutherford and the Bents in Peeblesshire. Crossing the country in a north-easterly direction, mountain limestone forms much of high ground, running

from Arniston to the neighbourhood of Tranent, and may be examined in numerous openings with facility.

At Crichton Dean, near the village of Fala, limestone is extensively worked; the same belt also crops out at the village of Salton and at the farm of Jerusalem, and several miles to the south a similar rock is quarried at Kidlaw, a point on the immediate confines of the greywacke strata. At Sunnyside a farm near Traprainlaw, a considerable deposit of limestone appears connected with the red sandstone series, and associated with trap rocks. Limestone again occurs near Balgone, forming, in all likelihood, a portion of that fetid limestone deposit which is worked at Rhodes, near North Berwick. Interstratified with the white sandstone which forms the coast of East Lothian from Broxburn to the Cove shore, there occur several strata of mountain limestone: the points where it is best seen are at Laurie's Den, Barness Point, and a little to the south of St Dennis' Chapel. To the north of the calcareous formation which we have described as forming a considerable extent of country, and skirting the base of the Moorfoot Hills, limestone has been extensively worked at the village of Burdie House, and can be traced to the neighbourhood of Gilmerton, where it disappears under the white sandstone. Near Tranent limestone is met with in one or two places; and it crops out also at several points on the shore between Aberlady and Red House.

In Linlithgowshire, though the great abundance of trap rocks, and the covered state of the surface, render the tracing of strata a matter of no small difficulty, and in many cases one of impossibility, still one band of limestone is found crossing the country in a N. N. E. and S. S. W. direction, in a well marked manner. The most southern point in the county where this limestone is visible is at

Blackburn, and around Bathgate it is completely exposed by the extensive workings of Kirkton, Petershill, Galla Braes, North and South Silver Mines, Wardlaw, and Hill House. In the neighbourhood of Linlithgow the limestone appears again at Bowden and Carruthers, and terminates in the sea near Borrowstownness. Near Dechmont Law, at Kirkliston, Newton, and Port Edgar, quarrying operations have exposed several other limestones, all of which are probably more or less connected. Concerning the distribution of the white sandstone series, little need be said, since, if we except the various ignigenous masses, it forms all that portion of the Lothians which is not occupied by the three formations, the boundaries of which we have endeavoured to assign. In regard to the localities of the igneous rocks of the Lothians, nothing here requires to be noticed, as these have been already detailed with sufficient minuteness, when considering their associations with the Neptunian strata.

We have given a more or less particular relation of the geognostical structure of the three Lothians, and shall now, by a short description, connect it with those parts of the county of Fife, which form the northern coast of the Firth of Forth.

The strata which are met with in Fifeshire may be referred to three series, viz. the red sandstone, the mountain limestone, and the white or carboniferous sandstone; all of which, however, in their modes of relative association, are precisely similar to the secondary stratified system of the Lothians. The lowest member of the stratified series of Fife is, as in the counties of Haddington and Edinburgh, the red sandstone; it passes insensibly into the white sandstone, with which it alternates both on the large and small scale. The mountain limestone is, it is needless to state, not a formation situated between the red and white

sandstone systems, but, on the contrary, exists only as a subordinate alternating rock. Partial examination of this system may lead some into error, as a similar mode of investigating the structure of the Lothians and other districts has done; but thorough scrutiny will convince, that the sandstones and limestones of Fife constitute a group which cannot be geologically subdivided. The origin of all its members has been strictly contemporaneous, and the causes which have produced these strata, have, from their commencement to their termination, been of the same general nature.* As points where the connection of the red with the white sandstone can be well observed, we may notice, the sea-coast extending between Dysart and Wemyss, and that which stretches from Crail to Fifeness; the course of the river Eden, also, and the country in its immediate neighbourhood, exhibit, in a clear manner, the relations of the two series to each other. The ignigenous masses which rise through the stratified rocks of Fife, are of the same general description as those which occur in the Lothians, inasmuch as they consist of various porphyries, greenstones, basalts, and tufas, and the changes which these have produced on the Neptunian rocks with which they are associated, are in numerous places of a highly interesting nature.

* In their organic contents, the rocks of Fifeshire are highly important, and deserve, as those of the Lothians, diligent and minute examination. The coal mines of this quarter also afford to the geologist much that is interesting in the economical department of the science. These subjects at present we do not intend to investigate, but on a future occasion we hope to lay before the Wernerian Natural History Society, a somewhat detailed account of the mines in the coal-field of Fife and the Lothians, and also a more or less perfect list of the vegetable and animal relics found in the several strata of these districts.

We shall now describe the geological phenomena which are to be observed on that part of the coast of Fifeshire which lies immediately opposite to the county of Edinburgh. It is one of the interesting tracts annually visited and explained to his pupils by Professor Jameson.

The North Queensferry is situated on a promontory composed almost entirely of greenstone, the felspar of which sometimes becomes of a brick-red colour, and occurs in a quantity sufficient to produce the syenitic aspect. In structure, it very generally exhibits the globular concretionary arrangement; the concretions varying in size from an inch in diameter, to an irregularly formed mass of several feet in length and breadth. On the road between the North Ferry and Inverkeithing there are several fine displays of this structure, and the atmospherical agents having acted on the softer and more easily decomposed base of greenstone, cause the globular masses to stand out in strong relief. Contemporaneous veins of greenstone traverse in considerable numbers indiscriminately the globular concretions and the bases in which they are imbedded. Veins of calcareous spar also occur: these, however, never cross the globular concretions of greenstone. In regard to the connexion of this body of trap with the sandstone, there are no intimate relations exhibited; near the toll-house between Inverkeithing and the Ferry, sandstone strata, dipping N. N.W. at 20°, are visible in a small bay which is entirely surrounded by trap. On proceeding along the shore from Inverkeithing to St David's, a junction of the greenstone with the slate-clay and bituminous shale has been exposed in searching for coal; no induration is, however, evinced, but, on the contrary, the strata appear to have a greater tendency to decomposition when near the trap than in those parts farther removed from it.

Near the point which constitutes the eastern boundary of Inverkeithing bay, a tufa occurs which forms mural sea-cliffs for a considerable way, and in some parts differs in character from those tufas which are so frequently met with associated with the trap rocks of the Lothians. It is composed very generally of a yellowish-white claystone felspar, in which variously shaped and sized masses of felspar, greenstone, bituminous shale, and sandstone, are imbedded, and passes into a tufa, of which the basis is an earthy greenstone, containing greenstone fragments which are sometimes amygdaloidal. Throughout the whole extent of this tufa there are indications of a more or less perfectly bedded structure, the separations into strata being produced by a change in the size of the imbedded fragments. The connexion of the sandstone with the tufa is in two places exposed: at one of these, which is near St David's, it exhibits numerous marks of derangement; and a series of strata, consisting of alternations of blackish and white slaty sandstone, which is shifted in one place for several inches, is thrust up amongst a completely compact white sandstone.

The other point where the junction of the two rocks is visible, is at the eastern extremity of the tufaceous mass; there, a vertical stratum of sandstone, several yards in height, by about three feet in breadth, is completely enveloped in it, standing out from the strata of tufa which, on both sides of it, have a westerly inclination. In regard to position and structure, there are appearances in both which indicate, that in the tufa there had been a cause adequate for displacement, and also for producing a change in mineral structure; for masses of the sandstone are bent amongst the tufa, and, as sandstones in contact with the more crystalline trap aggregates, become intensely indurated, and make the usual transition into quartz rock.

From this junction of the sandstone with the tufa to

Downing Point, there occurs only an uninteresting similarity of trap; it rests upon a thin series of strata of sandstone, but their more intimate relations are, as is generally the case in this part of the coast, much obscured by a thick covering of debris and vegetable soil;—the sandstone abuts, however, against the trap of the Point. On the shore opposite the House of Dunibristle, the strata change their W. N.W. dip, for one to the E. S.E., and continue to plunge in this direction as far as the old church of Dalgety, where, after lying for a short distance in an undulatory horizontal position, they are again found to sink to the W. N.W., inclosing a parallel vein of greenstone, and abutting against the trap hill of Braefoot. On the east side of Braefoot strata of white sandstone are met with, having the same inclination, and continue to form the shore as far as Aberdour, a little to the west of which two dykes of trap occur, one of which appears to have risen through the strata and tilted them up on both sides.

At Aberdour, on the western side of the harbour, a greenstone cliff exhibits phenomena of a most satisfactory nature in regard to its connexion with Neptunian rocks. (Plate XIV.) The lowest visible rock on which the trap rests is a white sandstone, which is exposed only for a few feet, and is separated from another stratum of sandstone by a mass of greenstone about two feet in breadth; this second mass presents in one part a slight flexure, and, as all the other masses included in this cliff of trap, gradually thins out at its western extremity. Above these two included portions of sandstone another one occurs, and also three imbedded fragments of shale; they vary in breadth from half a foot to the most delicate thread, and are completely changed in character; the sandstone becoming quartzose, and the shales assuming a compact structure. On the other side of the harbour the same arrangement is visible; the

sandstone again appears underneath the greenstone, and at the junction, and for a considerable distance from it, completely changes it into a characteristic hornstone. The greenstone which overlies these sandstone strata runs boldly into the sea, presenting vertical cliffs. On their eastern side the sandstone strata are again met with dipping to the N. N.E. at about 18°, almost throughout their whole extent altered, and presenting characters little differing from those exhibited by the quartz rocks of primitive districts. The strata between this point and Burntisland afford nothing deserving detail; as sandstone, which dips in general to the north, forms, with the exception of one or two greenstone masses, the whole of the exposed rocks on the shore. On advancing into the interior of the country, there is a continuation of the same general system of rocks as is visible on the shore. The Bin Hill rises immediately to the north of Burntisland, and exposes at its base, and for a considerable way up its acclivity, strata of white sandstone and limestone. The rock which forms the principal mass of the Bin Hill, is a coarse and easily disintegrated tufa, composed of variously sized masses of trap rocks, limestone, shale, and sandstone, imbedded in a base of earthy trap, and is traversed in one part by a dyke of basalt, containing numerous crystals of glassy felspar, and exhibiting an imperfectly columnar structure. Natrolite is found in the tufa in the form of imbedded amygdaloidal concretions. On the east side of the Bin Hill the same series of strata appears which is seen on the west, all dipping to the E. N.E. Basalt occurs, forming a vein running parallel with these, but the covered strata of the country prevents its relation to the sandstone or tufa from being made out. On advancing along the shore in the direction of Pettycur, no rocks are observed for a considerable way, the coast being entirely

formed of a flat sandy beach. Near Whinny-hall, however, and a short distance from the shore, a range of greenstone cliffs exhibits some interesting appearances;—the trap rises through the slate and sandstone strata, and from the lower side of an overlying portion, a mass of greenstone issues. All the strata, when in contact with the plutonic rock, are highly indurated, the slates acquiring the compactness of jasper and Lydian stone, and the sandstone passing into granular quartz-rock. Masses also of the slate are entangled in the greenstone, some of which are so changed as almost to put on the appearance of striped Siberian jasper. In their position these slates evince much disturbance, and are convoluted to a considerable distance from the greenstone. (Plate XV., Fig. 1.) Near this, the extensive opening of Whinny Brae quarry has exposed some interesting phenomena. The strata are alternations of sandstone, limestone, slate-clay, bituminous shale, and clay-ironstone, with an included parallel vein of claystone, all of which sink to the E. N.E. at an angle of 25°. In their course the rocks exhibit two gentle undulations, and are shifted in one place to a considerable extent. Near the eastern extremity of the claystone, the mean breadth of which does not appear to be more than three feet, a vein of about a foot in breadth issues from its under surface; it crosses the shale strata at an angle of about 70°, and is probably connected with a lower mass of felspar, which the quarrying operations have exposed. In regard to the effects of this claystone on the strata, they are completely demonstrative of its violent protrusion and former highly heated state. Masses of the shale are imbedded in it in innumerable places, and it is traversed near the junction by an infinity of small felspar veins. In some places the slate appears to have been fractured into minute fragments, which have been subsequently

agglutinated by the infusion of the felspar; and in other parts masses of the shale are bent up amongst the felspar, and made to assume the form of a vein; the structure is also completely changed, inasmuch as the perfectly fissile slate-clay assumes a hardness which, in some parts, is little inferior to that of Lydian stone. (Plate XV. Fig 2.)

Alexander's Craig, which forms a high traprange near this, is composed of irregular alternations of tufa and amygdaloid, surmounted by a range of an imperfectly prismatic basalt, which reposes on thin strata of slate-clay, ironstone, and sandstone; in one part it is in immediate contact with a bed of coal, a portion of which is entangled in the basalt and completely charred. Veins of fibrous calcareous spar abound, traversing both the tufa and the strata. From Alexander's Craig to Pettycur, the rocks are entirely composed of amygdaloid with tufa, in which numerous variously sized masses of slate are imbedded. Calcareous spar occurs in great quantities, forming large veins and amygdaloidal masses in the greenstone, and is in some places associated with groups of amethyst and quartz crystals. On the shore at Pettycur, the amygdaloid reposes immediately on much indurated strata of mountain limestone; and, at one point, both rocks have been shifted for several feet. Superimposed on the amygdaloid which lies on the limestone, there rests a thin series of ironstone and shale strata, above which amygdaloid again occurs. Immediately below the inn of Pettycur, there begins an alternating series of sandstone, limestone, shale, basalt, amygdaloid, greenstone, tufa, and wacke; all these rocks dip to the east, and continue with little interruption till within a short distance of Kirkaldy. Though the alternations of the neptunian and plutonic rocks are so numerous, still there are only a few places where their connections exhibit any thing interesting, and with a detail of

two of the most conspicuous of these we shall conclude this short account of the southern coast of Fife. The first object of interest to be observed in proceeding along the coast, is at a short distance to the east of the village of Kinghorn, where a stratum of white sandstone is completely enveloped in the greenstone. It varies in breadth in different places, and in those parts which are thinnest becomes completely changed into quartz rock, while in the others there is a gradual transition made from a quartz rock at the junction with the trap, to a sandstone, forming the more central parts of the stratum. It exhibits a slightly undulating position, and splits easily into irregularly-shaped masses, in a direction more or less at right angles to the plane of the bed. The other point where interesting phenomena are displayed is at Tyrie Bleachfield, a point almost at the extremity of this series of rocks. Here a mass of greenstone, presenting the ordinary character, occurs, and having the same N. E. dip as the other rocks of the coast; it rests in one part on thin strata of black slaty sandstone, and in another on a white sandstone. Lying immediately below the white sandstone, and in contact with it, a vein of claystone-felspar appears, identical with that of Whinny Brae quarry; it traverses strata of black slaty sandstone and shale, and finally is seen to thin out between them and a stratum of white sandstone, inferior to that upon which the overlying greenstone mass rests. In its course, this vein of felspar gives off minute veins, and is also shifted in two places, a proof in addition to that which the Whinny Brae quarry exhibits, that disturbing influences had operated after the eruption and consolidation of these igneous rocks. Below the lowest series of black slaty sandstone and shale strata, a bed of limestone occurs, resting on one

of coal, and the group of sandstone strata which forms the lowest of the rocks visible in this section. (Plate XVI.)

From this point to Kirkaldy, a flat sandy beach completely covers the subjacent rocks; to the east of the town, however, the sandstone-slate and shale again appear, and continue onwards for a long way.

In the more central parts of Fife, there are numerous points where the relations of the trap-rocks to the neptunian strata are interesting, and we shall conclude with a notice of the geological appearances exhibited in the Lomond hills. The Lomond hills consist of three eminences, Easter, Wester, and Mid Lomond, the two first rising to the heights of 1466 and 1721 feet. When viewed from a distance, these hills might, from their external appearance, be considered as entirely composed of trap-rocks; on examining them, however, it is found that a very considerable portion consists of the coal sandstone, and on the north side of the Wester and Mid Lomonds, a section, extending from the foot almost to the summit of the hills, exposes their structure in the most satisfactory manner. Red sandstone dipping S. W. at 8°, is the lowest rock visible, and forms the most of that comparatively level country which skirts their northern base, being succeeded by the coal series of white sandstone, slate-clay, and clay-ironstone, which is surmounted by the great overlying trap deposit of the hills. Wester Lomond rises immediately above Loch Leven, and presents a front of more or less regularly columnar trap. In several places the quarrying of the sandstone, for the purpose of building, has exposed immediate junctions of the two classes of rocks; but in no instance do the strata afford appearances of induration: near their contact with the greenstone, however, they in some places occur in positions which can only be considered as disturbed.

On crossing the trap ridge of Wester Lomond, horizontal strata of mountain limestone are found resting upon it. Quarrying operations have not as yet exposed the greenstone on which this limestone reposes, but its aspect throughout its whole visible extent is a sufficient proof that it has been influenced in no inconsiderable degree by the agency of the trap. The smooth conchoidal fracture, the earthy appearance, and uncrystalline arrangement, of the mountain limestone have all been removed, and a rock produced which in many places, is perfectly crystalline in its structure, and of various shades of grey and white. The usual corals and madrepores occur in this limestone, and, in their states of preservation, vary from one, which in the rock when little altered, is almost perfect, to that more or less obliterated appearance which they present when found in the completely altered limestone.

The trap forming the range of Wester Lomond, is a greenstone which varies from large to small granular; it is in general arranged in concretions having a tendency to the prismatic form; but, in some places, it displays, in the most marked manner, the globular appearance. Mid-Lomond, as we have before stated, is, in its lower part, composed of sandstone strata, and in the upper of trap. Induration is, however, in no instance to be observed. On the side of the valley which separates this hill from Wester Lomond the trap may be found alternating several times with the sandstone; the state of the surface, however, prevents us from examining the appearances exhibited at the junction of the two classes of rock. The trap-rock which forms the lower parts of Mid-Lomond, is an ordinary greenstone with somewhat of a prismatic structure; the summit, however, and a considerable part of the southern acclivity, is entirely composed of a well characterized greyish-black basalt, which

is in one or two places arranged in an irregularly tabular manner. The structure of Easter Lomond is precisely similar to that of the two hills we have just described, and in no place are there any appearances which render a detailed description necessary. Throughout the whole extent of this highly picturesque and beautiful range of trap hills, no point can be fixed on as one through which the igneous matters which alternate with and cover the sandstones have been erupted: the almost perfect horizontality of the strata is, however, a sufficient indication that these trap-rocks are to be considered more or less as portions of plutonic streams, which, on being erupted, have flowed over horizontal surfaces. Separating the hills of Wester and Mid Lomond, there is a ravine which is interesting, inasmuch as it has evidently been produced by a great rent running through the parallel and horizontal beds of aqueous and igneous rocks, which form these hills: no one, however, when viewing them, and observing the perfect agreement of the beds of the one hill with those of the other, can ever consider this ravine as original, nor can any one, with any degree of propriety, refer it to the action of the rivulet. When describing the trap-rocks in the vicinity of Edinburgh, we have remarked that they, as well as the strata on which they repose, frequently present abrupt and broken fronts: of this the Lomond hills on their northern side exhibit an excellent example; and the horizontality of the beds renders it probable that this aspect has been produced contemporaneously with the protrusion of the ignigenous masses.

We have now described at considerable length the geology of the Lothians, having endeavoured to notice every locality which in our investigations appeared worthy of detail, and every rock which afforded to us any thing interesting,

either in regard to its mineral characters or mode of connexion with others. Notwithstanding that an observer spends much time in investigating a given tract, and pursues his labour with much alacrity and diligence, still when he has completed his survey, though he has travelled through the country in every direction, having climbed its mountains and perambulated its valleys, coasts, and streams, some points, perhaps, even of considerable interest, may have been passed over by him unobserved. Aware of this, however, we sincerely hope, that though geologists, in examining the district which we have been considering, may find appearances which we have not described, they will not, when comparing our descriptions with phenomena in the field, discover that in any instance we have misunderstood what we saw. Throughout the whole of this paper, we have endeavoured to state, in the most concise manner, what we considered requisite to notice, doing this from a conviction, that in writing upon natural appearances, a multiplication of words is to be particularly guarded against. In conclusion we may only remark, that if we have endeavoured to advocate doctrines considered as erroneous by some observers of celebrity, and have differed from others in descriptive details, we have in the one case done so from no love of disputation, and in the other, from only finding in the district which we have examined appearances which seemed to us capable of being only seen in one way.

APPENDIX I.

SIR JAMES HALL'S EXPERIMENTS.

When describing the relations of the trap-rocks of the Lothians to the Neptunian strata, we have casually remarked, that it was from an examination of them that Dr Hutton first formed those theoretical opinions concerning their mode of formation, which are now universally adopted by the cultivators of geological science. From Salisbury Crags, Arthur Seat, and numerous other points in the district of the Lothians, that ingenious philosopher and acute observer drew conclusions in regard to the past history of the world which, even on their first proposal, were adopted by many, and zealously defended by not a few. In the present advanced state of geology, it may appear to some that the several phenomena which Dr Hutton first pointed out in regard to the trap-rocks, and the appearances which the individuals of the stratified systems exhibited, when near them, were of so clear a nature, that they could be explained only in one way; but it must be remembered that the plutonic origin which he awarded to the trap-rocks, and the changed state in which he said certain strata existed, were as yet to be considered as theoretical, and could not be proved by direct experiment. Compression under water or solid strata had been stated to be a cause sufficient for the production of a crystalline structure in masses cooling down from an original state of igneous fusion, but the chemist had not as yet demonstrated this by making a homogeneous vitreous mass acquire a granular arrangement.

If Hutton, however, proposed the theory of the unstratified rocks, it was left for Sir James Hall to establish its truth, by a series of original experiments which will make his name ever be respected by the scientific world, and ever have a prominent place in the page of geological history. To this distinguished examiner, the crystalline structure of granite, porphyry, and trap, appeared at first to contradict the hypothesis of Dr Hutton; but the experiments which he made with such success, convinced him that the effects of compression were of a gigantic character, and that differences in it might account for the dissimilarity of aspect which exists between a trap or a Plutonic rock, and a lava or a Volcanic rock As the experiments of Sir James Hall on "Whinstone" (Trans. of Royal Society of Edin. v. 5.) were made on several well known rocks in the neighbourhood of Edinburgh, which we have already described, we shall briefly extract, from his paper in the Transactions of the Royal Society, a few particulars in regard to this interesting subject.

The first trap-rock which was examined was the greenstone of Bell's Mills, a point which, in its proper place, we have already noticed. A black-lead crucible filled with fragments of this stone was introduced into the reverberating furnace of an iron foundry; having remained there a quarter of an hour, the greenstone became completely fused and was agitated with a violent ebullition, and on being removed from the furnace and allowed to cool rapidly, was found to have lost its crystalline arrangement, and to have assumed a vitreous aspect. It was thus found that fused greenstone when quickly cooled has not a granular structure.

In subsequent experiments, Sir James Hall endeavoured, by slow and gradual cooling, to cause the trap to assume its original characters. The first attempts which were made

to effect this object were only partially successful; the product of the slow refrigeration was not in a vitreous state, but still it had not the crystalline appearance of the whinstone; sometimes it had a liver-like appearance, and at others was a dull vitreous mass, containing innumerable little spheroids and having a dull earthy fracture; at last, however, Sir James succeeded completely in the object which he had in view. A crucible, containing melted greenstone, was removed from the reverberatory, placed in a large open fire, and surrounded with burning coals. The fire "after being maintained for several hours was allowed to go out, and the crucible when cold was broken, and was found to contain a substance differing in all respects from glass, and in texture completely resembling whinstone. Its fracture was rough, stony, and crystalline; and a number of shining facettes were interspersed through the whole mass. The crystallization was still more apparent in cavities produced by air bubbles, the internal surface of which was lined with distinct crystals."—P. 48. The fragments of greenstone, however, which had been thus artificially crystallized had not been previously reduced to the state of glass, and therefore the experiment might be liable to rejection as inconclusive by those who advocated Neptunian principles. To obviate this, however, Sir James Hall determined, on the suggestion of Dr Hope, the Professor of Chemistry, to "reduce the stone first to glass, and to perform the crystallization after the second fusion."

We shall now notice the results which were obtained. The greenstone of Bell's Mills was fused and quickly cooled into a black glass, as in former experiments; "a crucible, filled with fragments of this glass, being then exposed to a heat, which from previous trials was judged to be more than sufficient to reduce its contents to fusion, the fire was

very gradually lowered till all was cold."—P. 49. On the crucible being examined, Sir James was in no small degree surprised to find that " the fragments had never been in complete fusion, since they still, in a great measure, retained their original shape."

In another experiment the trap-glass was completely fused, the temperature of the fire was reduced to about 28° of Wedgwood's pyrometer, and allowed to remain so for six hours. " The result was a perfectly solid mass, crystallized to a certain depth from the outside, though still vitreous in the heart ;" a similar mass of glass, however, being experimented on in the same manner, but being subjected to the heat for twelve hours, was on its consolidation " entirely crystalline and stony throughout."

On investigating the fusibility of the glass obtained by melting the greenstone of Bell's Mills, from experiment it occurred to Sir James Hall, that the fact of the trap-glass not thoroughly fusing on a former occasion, was to be explained by supposing that, on the first application of heat, it had partially softened, and then had crystallized so as to become again rigid, and that in the crystallizing process, " it had acquired such infusibility as to yield to no heat under 30°."

We shall quote from Sir James Hall's paper the experiment by which he confirmed this conjecture. " A piece of the same glass (the trap-glass), placed in a cup of clay, was introduced into a muffle, heated to 21°. In one minute it became quite soft, so as to yield readily to the pressure of an iron rod. After a second minute had elapsed, the fragment, being touched by the rod, was found to be quite hard, though the temperature had remained stationary. The substance, thus hardened, had undergone a change throughout ; it had lost the vitreous character ; when broken, it

exhibited a fracture like that of porcelain, with little lustre; and its colour was changed from black to dark brown. Being exposed to heat, it was found to be fusible only at 31°; that is, it was less fusible than the glass by 13° or 14°.

"Numerous and varied experiments have since proved, in the clearest manner, that, in any temperature, from 21° to 28° inclusive, the glass of this whin passes from a soft, or liquid state, to a solid one, in consequence of crystallization; which is differently performed at different points of this range. In the lower points, as at 23, it is rapid and imperfect; in higher points, slower and more complete, every intermediate temperature affording an intermediate result. I likewise found, that crystallization takes place, not only when the heat is stationary, but likewise when rising or sinking, provided its progress through the range just mentioned is not too rapid. Thus, if the heat of the substance, after fusion, exceeds one minute in passing from 21° to 23°, or from 23° to 21°, the mass will infallibly crystallize, and lose its vitreous character. These facts enabled me to account for the production of the substance resembling the liver of an animal, which I obtained in my first attempts to crystallize the melted stone. Not being then aware of the temperature proper for complete crystallization, I had allowed it to be passed over rapidly by the descending heat, and I had begun the slow cooling in those lower points, at which the formation of this intermediate substance takes place.

"By the same means I was enabled to explain the unexpected result, which I obtained in endeavouring to convert the glass of this stone into crystallite.* The fire applied to the crucible, containing fragments of the glass, had been

* The crystallized substance, obtained from the slow cooling of trap-glass, was denominated crystallite by Sir James Hall.

raised very slowly, which I know to have been the case by some circumstances of the experiment. The glass had softened by the first application of heat, but had crystallized again as the heat gradually rose; so that the substance consolidated, while still so viscid as to retain the original shape of the fragments; at the same time it acquired such infusibility as to resist the application of higher degrees of heat during the rest of the process." (Trans. of Royal Soc. of Edin. vol. v. p. 5.) Besides the greenstone of Bell's Mills, Sir James Hall fused and recrystallized several other of the trap-rocks around Edinburgh. We shall note his observations in regard to these.

Whin (Basaltic Clinkstone) *of the rock of Edinburgh Castle.*

"The pure glass which this whin yielded, by rapid cooling after a moderate heat, was crystallized in three experiments, and produced masses greatly resembling the original. In one of these, formed on a large scale in the glass-house, the resemblance is so strong, both as to colour and texture, that it would be difficult, or perhaps impossible, to distinguish them, but for a few minute air-bubbles visible in the artificial crystallite. The glass is less fusible than that resulting from the greenstone of Bell's Mills, and seems not to possess the property of producing the liver crystallite." —p. 53.

Whin of the basaltic columns on Arthur's Seat, near Edinburgh.
(Basalt of the summit.)

"In the temperature of 100° or upwards, the whole was changed to pure black glass; but in a more moderate heat (about 60°), the felspar remained unchanged, while the hornblende disappeared and formed a glass along with the basis of the stone. Both kinds of glass yielded highly cha-

racterized crystallites, that last mentioned having its felspars entire, produced a substance like porphyry, in which the white felspars were imbedded in a black crystalline basis. The crystals formed in this basis are so complete in one example, that they are seen projecting into the cavities and standing erect on the external surface so as to make it sparkle all over. These black crystals seem to be hornblende of new formation. We have found by some late experiments that they are considerably more refractory than the crystallite in which they lie, and are equally infusible with some species of natural hornblende."—P. 53.

Whin (Basalt) *from the neighbourhood af Duddingston Loch.*

"Its glass yields a fine grained crystallite, like to that of the greenstone of Bell's Mills."—P. 54.

Whin (Greenstone) *of Salisbury Crags.*

"Its glass yielded a highly facetted crystallite, approaching to the structure of the unfused basalt of Duddingston Loch."—P. 54.

Whin (Syenitic Greenstone) *from the rolled masses in the bed of the Water of Leith.*

"In fusion and crystallization it resembled the other whins."—P. 55.

Whin (Basalt) *of the basaltic columns of Staffa.*

"It yielded a perfect and very hard glass, which, in a regulated heat, produced a uniform stony crystallite, greatly resembling the original."—P. 55.

Having performed the experiments on whinstone, the unerupted lava of the philosopher whose opinions he had adopted, Sir James Hall engaged in a series of experiments

on mineral masses, the evident volcanic origin of which was admitted by all. From his original paper we shall extract the results to which this examination led.

Lava of Catania (Basaltic Lava).

"After strong heat, the whole was reduced by rapid cooling, to pure black glass; but, when the heat applied was moderate, the felspars remained unchanged. Being maintained, after a second fusion, in a temperature of 28° (Wedgwood) both these glasses yielded strong and crystallized substances somewhat less fusible than the original, and, when exposed to a temperature of 22°, they crystallized rapidly like most of the whins (trap-rocks) into the liver crystallite. This last property is common to all the lavas." —P. 60.

Lava of Sta. Venere.

"The pure black glass formed from this lava yielded, in the regulated heat, the most highly crystallized mass we have obtained from any lava or whin."—P. 61.

Lava of La Motta di Catania.

"Its glass yielded a dark grey crystallite of uniform texture."—P. 62.

Lava of Torre del Grecco.

"It was found to be less fusible than any of the others, yet its glass crystallized in a lower temperature."—P. 63.

Lava of Vesuvius, eruption 1785.

Sir James Hall, after examining with care a lava stream which flowed from Vesuvius, found that it completely resembled the glass obtained from the rapid cooling of an ar-

tificially fused mass of lava. "Besides all other properties," he remarks, "it possesses the fusibility of the glasses, since it softens completely at 18, that is 14 or 15 degrees below the softening point of any of the stony lavas. Being exposed to the process of regulated cooling, it gave the same result as all the other lava glasses. In the lower points it yielded a liver crystallite infusible under 30, and in the higher a stony substance like a common lava or whin, and fusible only at 35."

We here extract from Sir James Hall's paper the Table of the fusibilities of the traps and lavas which he examined, and from it "it may be observed that the original whins soften in a range from 38 to 55, the glasses from 15 to 24, and the artificial crystallite from 32 to 45."

Substances.	Original softened.	Glass softened.	Crystallite softened.
Whin (Greenstone) of Bell's Mills Quarry,	40	15	32
Whin (Basaltic Clinkstone) of Castle Rock, . . .	45	22	35
Whin of basaltic column, Arthur's Seat, ...	55	18	35
Whin (Basalt) near Duddingston Loch, ...	53	24	38
Whin (Greenstone) of Salisbury Crags, ...	55	24	38
Whin (Syenitic Greenstone) Water of Leith, . . .	35	16	37
Whin (Basalt) of Staffa, . .	38	14½	35
Lava of Catania, ...	33	18	38
Lava of Sta. Venere, Piedmont, .	32	18	36
Lava of La Motta, . . .	36	18	36
Lava ? of Iceland, . . .	35	15	45
Lava of Torre del Grecco, . .	40	18	28
Lava of Vesuvius, 1785, . .	18	18	35

The other discoveries of Sir James Hall we need not here notice in detail. His experiments on limestone and coal are

known to both the chemist and the geologist, having to the latter afforded explanations of appearances of no little complexity, and to the interest excited by his investigations are, in no small degree, to be traced many discoveries which have been made by Continental philosophers. To the geologist and chemist of the present day, the experiments of Hall tell that a vast field is open for investigation; and examinations, philosophically conducted on the grand principles which he chalked out, would, it may with certainty be stated, either corroborate the truth of certain, as yet, theoretical points in geology, or display their falsity. By furnace experiments knowledge could be gained, in all probability, on much which is now the "Terra Incognita" of geology. How is dolmitization effected? Are the granites, the porphyries, the trap-rocks, trachytes, and lavas to be considered only as links in a connected chain of igneous elaborations, of which the one extremity is granite and the other lava, the differences in mineral structure and composition being effected by differences in compression, and in the rocks with which they have come in contact? Do the various stratified deposits contribute to the formation of igneous rocks; and can sandstones, shales, and conglomerates be made to assume characters indicative that the formations of gneiss, mica-slate, hornblende rock, and the several strata denominated Primitive, are only to be considered as mechanical deposits, which have been completely altered? All these are questions which it is of the highest importance to solve, and solutions appear only to be got in experimenting on mineral masses, at very high temperatures, and under great compression.

APPENDIX II.

ON THE JUNCTIONS OF GREYWACKE AND SANDSTONE WITH GRANITE AND SYENITE.

In our memoir on the Geology of the Lothians, we have observed that the Transition strata are in few instances connected with the ignigenous rocks, and that even when such relations are observable, they are seldom of an interesting description. Other portions, however, of the great transition high land of the south of Scotland are related, in an interesting manner, with plutonic masses. Trap and porphyry rocks in several places occur associated with the strata, but a detail of the appearances exhibited by these is here inadmissible; we shall, however, shortly notice a few points where they are found connected with true granite and syenite.

The granitic rocks which rise through the greywacke strata form three distinct and isolated groups, viz. that of Criffel, Loch Ken, and Loch Doon.

I. *Criffel District.**

The first of these, near the village of New Abbey, rises through the greywacke and attains in the hill of Criffel to the height of 1830 feet. The granitic rocks of this district do not consist entirely of true granite; on the contrary, they vary much, some of the mountains being formed of granite, while others are composed of a characteristic syenite. None of these rocks, however, in their relations to each other, indicate a difference in age, but bear impressed upon them characters which prove a perfect synchronism

* Vide Professor Jameson's Memoir on the Geognosy of Criffel, Kirkbean, and the Needle's Eye in Galloway, in the 4th volume of the Memoirs of the Wernerian Society.

of formation. The felspar which enters into the composition of the granite and syenite varies in colour from white to grey and light brick-red, while the quartz is invariably of the usual grey colour ; the mica is in general brown, and occurs only in minute scales. In several places, the granite assumes a porphyritic aspect, the crystals which produce this arrangement being invariably of felspar ; but on the large scale there is no example of determinate structure,—that tabular appearance which is so often to be observed in extensive granite districts never occurring here. The syenite which is associated with the true granite is, like it, small granular, and from the hornblende varying in quantity, the rock assumes various aspects. Sphene occurs in minute crystals, and may be observed in the syenitic cliffs about two miles to the north of New Abbey. Contemporaneous veins occur in the granite and syenite, and appear to have been produced during a state of the rock capable of allowing the free motion of its constituent minerals ; some of these veins are composed of quartz, while others consist of a granite of a smaller grain than that which they traverse. They run courses more or less tortuous, pass more or less into the bounding walls, and when well exposed may be found thinning completely out at both extremities. On examining any considerable tract of this country, numerous concretionary masses are to be observed in the syenite. They vary from a small size to one or two feet, being either of angular or ovoidal shapes, and in general are composed principally of hornblende; frequently all the constituents of the syenite, however, enter into the composition of these masses, and sometimes they become porphyritic by containing crystals of felspar. In regard to the appearance of the concretions at the planes of contact with the rock in which they occur, it may be remarked

that they vary from a perfect distinct boundary line to one of the most indefinite character, one in which the minerals of the rock containing the concretions occur interlaminated with those of the concretion.

We shall now detail the relations of the granite to the greywacke, which are observable at two points. The Needle's-Eye, a perforated rock which occurs near the mouth of the Southwick water, is a point where both rocks may be found in immediate connection, and the first appearance, which is most striking, is the intimate blending of the one with the other. The whole scene in this respect is one of the greatest confusion, and certainly if the igneous origin of granite were not supported by appearances more indicative of a plutonic formation than those observable here, its synchronism with the greywacke, and perfect similarity of formation, would be based on no insecure foundation.

To describe all the minute modes of junction of the greywacke and the granite at this point would, if the nature of the ground did not render it impossible, be an unnecessary labour; we shall, however, give a detailed account of their junction taken as a whole. When considered as a mass the granite of this point appears to be chiefly distributed through the greywacke in the form of veins, which occur of all magnitudes, and run courses which in some instances are almost straight, while in others they are highly tortuous. On examining the immediate planes of junction of the granite with the greywacke, these will be found to vary much in appearance, sometimes both rocks having a decided and well marked boundary, while at other times they make a gradual transition into each other. Throughout the same vein both of these appearances may sometimes be observed; one part, in some instances, affording a distinct separation,

while in another there is so complete an intermixture, that it is almost impossible to tell where the one rock begins, and where the other ends. The size of the veins bears no relation to the degree of intermixture of them with the greywacke; on the contrary, a very large vein may pass into the rock, or it may not, or a small vein, in size perhaps not exceeding three or four lines, may be completely commingled with the greywacke which it traverses, or may have a determinate outline.

In its mineralogical structure, the rock which forms the veins frequently differs from that which constitutes the larger masses. The several components, the quartz, felspar, and mica, or the felspar, quartz, and hornblende, become intimately and obscurely intermixed with one another; and in many places the veins are composed of an intermixture of quartz and felspar, which is sometimes so perfect that the veins appear to be composed of a very compact felspar.

The appearances which the greywacke exhibits when in the neighbourhood of the granite and syenite, are expressive of indurating or altering causes: in every instance it becomes compact, the slaty varieties passing into a species of felspar, not unlike some clinkstones. In both the granite and the greywacke, shifts may in some places be observed; the sides of these shifts, however, are so intimately connected as to render it highly probable that they have taken place before the granite was in a perfectly consolidated state. In regard to the stratification of the greywacke, it varies in regularity; sometimes the rock being perfectly amorphous, while in other places it exhibits a more or less bedded structure, the strata then dipping to the S.S.E. at angles between 30° and 70°, and resting upon the principal mass of granite and syenite. In one or two places layers of quartz occur in the greywacke; in every instance, however, these are to be observed only near the granite; fi-

brous amethyst is also to be found at some points. Near an isolated rock called Lot's Wife, a vein of felspar-porphyry crosses the strata of greywacke, into which, at the planes of contact, it is gradually found to pass.

Having described the appearances at the Needle's Eye, we shall next notice some other localities where the greywacke is connected with granite.

On proceeding along the bank of the Ladyland burn, a streamlet which crosses the road about a mile and a half to the south of Kirkbean, the greywacke is found in various altered positions, dipping at high angles, and in some places also much contorted. In several parts veins of felspar porphyry cross the strata, but junctions are in no place visible. In mineralogical character these porphyry veins present a perfect similarity; they are composed of a compact light reddish-brown felspar with imbedded crystals of felspar, being identical, in every respect, with other porphyries associated with the same strata in other parts of this great transition district. As an examination of the bed of this burn appeared to afford a chance of again observing a junction of the syenite with the greywacke, we traced it through its whole extent, but unfortunately the desired contact was not visible. In the Kirkbean burn, however, almost at its source there is a distinct exhibition of the junctional relations between the granite and the greywacke. In the other parts of the bed of this stream there is nothing interesting exposed: there are a few porphyry and felspar veins, but beyond their presence little else can be made out; they cross the strata and are frequently many yards in breadth. As in the other points where the contact of the granite and greywacke is exposed, the strata are here found to abut against the unstratified rocks at high angles. Some of the varieties are highly quartzose, and approach almost to sandstone. Concerning the characters of the

greywacke when next the granite they are interesting and completely different from those exhibited at the Needle's Eye, inasmuch as the slate invariably passes into a perfect slaty aggregate of brown micaceous scales. In regard to the positions of the two rocks to each other, they are rather remarkable: there is the most perfect intermixture, the one with the other; layers of granite, in many instances, not more than two or three lines in breadth occurring completely isolated in the strata, and without any visible connexion with the main mass of the rock. The very reverse of this is also, in many places to be observed, masses of the slate altered into brown mica, occurring imbedded in the granite. In their position these granitic masses enveloped in the slate agree with the greywacke, conforming in every instance with the contortions visible in it; a circumstance which very frequently attends junctions of granite with stratified rocks. At the planes of junction here there is never to be observed a well marked boundary line; on the contrary, there is a transition of both rocks into each other, of such a nature that, if a theory concerning the origin of granite were to be formed only from the phenomena of this point, it would incline any one to consider both mineral masses as merely modifications of each other, and the effect of one and the same cause or system of causes.

II. *Loch Ken District.**

Another group of granitic rocks is met with in the neighbourhood of Loch Ken in Kirkcudbright: as several junctions, however, of these rocks with the greywacke have been described in the Transactions of the Royal Society of Edinburgh, we shall here only notice a few localities shortly.

* The geognosy of this district is described by Dr Grierson in a memoir and map laid before the Wernerian Society, and published in the 3d volume of the Annals of Philosophy, and also in a memoir in the 2d volume of the Wernerian Memoirs, entitled "Mineralogical Observations on Galloway."

Proceeding from the village of New Galloway, down the western bank of Loch Ken, the greywacke strata are found ranging in a vertical position S. W. and N. E., a position which they preserve very generally over this country.

About a quarter of a mile to the south of the ancient castle of Kenmore we meet for the first time with the granite of the Ken district. It is here a compound of brick-red felspar, quartz, and mica, and for a considerable way the loch is skirted by a narrow band of the transition rocks. With the exception, however, of the junction of the Windy Shoulder, which has been described in the volume we have referred to, we only noticed one on the bank of the loch, and this is not traceable for more than a foot or a foot and a half. The greywacke, which, at a distance from the granite, is perfectly characteristic and similar to that of other quarters in the south of Scotland, acquires, on approaching it, the aspect of an indurated felspathic sandstone, containing a few very minute scales of mica; at the junctional planes it exhibits a tendency to pass into the granite, in a manner evincing, however, no greater or more remarkable changes than those which are often found attending junctions of trap-rocks with sandstones and shales.

The other point where we had an opportunity of examining junctional relations, was at the east end of Loch Stroan, and at this point the nature of the ground renders these more apparent. Near that part of the loch, from which the Black Water of Dee rushes, a vein of granite traverses the greywacke: it is not found in union with the principal mass, though its joining it near this is probable from the circumstance of the granite forming the bed of the loch here. The visible length of this granite vein is thirty feet, being at its greatest breadth one foot, from which it gradually diminishes until at last it terminates in a mere thread. Very generally a layer of massive quartz intervenes between the granite and the

greywacke, and traverses the latter in numerous veins. The greywacke is intimately connected with the granite at the junction; but there is no transition into any rock which can with any degree of propriety be referred to the primitive series of the Wernerian geognosy. The granite which occurs here is a compound of a yellowish-white felspar with the accompanying minerals of quartz and mica. Another locality which we examined for the purpose of noticing the altering effects of granite was at the old bridge of Dee, about half a mile to the south of Clatteringshaws toll-bar. The greywacke here is indurated, but it is still greywacke, and abuts at a considerable angle against the granite which has upraised it.

III. *Loch Doon District.**

The third granite group, which is associated with the strata of the south of Scotland, is that of the district of Loch Doon; and as connected with that metamorphic theory, which supposes that the gneiss and mica-slate strata are only altered sandstones and shales, the junctions exhibited in this quarter are interesting. To trace the connections of granite with its associated strata, and to examine the appearances observable at their junctions, has long been an object of geological investigation. In the generality of cases, however, this examination can only be made in regard to the contact of granite with rocks which, though stratified, are nevertheless a complete crystalline aggregate, and bear impressed upon them characters as completely indicative of a consolidation from a state of fluidity as the unstratified granitic masses which occur among them. If we wish to discover, therefore, whether such rocks have lost their original mechanical characters by the action of the granite, it is evident that we must endeavour to find an indubitable mechanical rock so connected with

* Vide Dr Grierson's Memoir on the "Mineralogy of Galloway," in vol. ii. Mem. Wern. Soc., for his description of the granite and greywacke junctions in this district.

granite, that it is to be considered in circumstances which are fitted for its undergoing a metamorphosis. It is not enough to state that gneiss and mica-slate are metamorphic ; but to prove that they are, it is necessary to find a mechanical deposit becoming a gneiss or mica-slate. If an object undergoes a metamorphosis, the fact of its having done so, is only to be believed from the evidence of the senses in witnessing the change, or from finding the original substance in all states between a complete and an incipient alteration.

The junction of granite and greywacke at Loch Doon, affords no support whatever to the doctrines to which we have alluded, and certainly if such a theory is tenable, this locality is one where we might expect to find appearances in favour of it. On both sides of the loch, a junction of the granite rocks with the greywacke is visible. On the west side, however, these appearances are best exposed, and we may remark that perhaps no part of Scotland exhibits, in a more clear or marked manner, the connections of granite with stratified rocks. For many yards the junctions of the two rocks are exposed in the most satisfactory manner, veins of granite traversing the vertical greywacke strata in all directions, and in some instances crossing them at various angles with the planes of stratification, while in others they run parallel with them. In breadth, the granite veins vary from six or seven feet to the smallest size, and at their planes of contact with the greywacke, there is in general an intimate commixture of both rocks, the larger granite veins containing numerous variously sized imbedded angular fragments of the greywacke. The rocks on the side of Loch Doon which exhibit the junction afford every facility for examination, and from the action of the water they are almost as smooth as if they had been polished by art : the veins even of the smallest size may, from their resisting the weather better than the greywacke,

and standing out in strong relief, be investigated throughout their most minute ramifications. As an interesting circumstance in regard to this junction, we may state, that the granite does not disturb the direction of the strata in any instance. Thus, although they are traversed in every possible manner, still they preserve the same N. and S. direction which they had when at a distance from the granite. It is to be particularly noticed also, that the lines of direction, when visible in the imbedded masses, agree with those of the strata.

At a distance from the granite, the greywacke of this district, exhibits only the usual aspect, but when in contact with it, it affords a different series of characters, and is then generally composed of very minute crystalline grains of white felspar and mica, with a slight intermixture of quartz. It has a perfect granular structure, and exhibits nothing which approaches either to gneiss or mica-slate, but, on the contrary, is only to be considered as a greywacke which has lost its mechanical aspect through the influence of the granite rocks which rise through it.* The granite of Loch Doon is of two kinds, the one being a compound of red felspar, quartz, and mica, the other of white felspar, quartz, and mica; hornblende frequently enters into its composition, producing then a characteristic syenite. The only structure observable is the tabular, but of this even there are no very marked examples.

IV. *Junction of Granite and Sandstone in Arran.*

The details we have just given, it is needless to say, prove that in Scotland there is a granite formation newer than the transition strata. We shall, however, adduce an instance of true mineralogical granite being also newer than the old red conglomerate.

* Dr Grierson, in his "Mineralogical Observations in Galloway," describes this altered greywacke as a compact gneiss.

The junctional appearances of the granite and sandstone, to which we refer, occur in the island of Arran, and are only to be observed in a stream which enters the sea near the village of Corry. At this point, when at a distance from the granite, strata of slate-clay and red sandstone are found dipping S. S.E. at 30°, the sandstone frequently passing into conglomerate, and containing rolled masses of quartz-rock. On advancing from the sea to the mountain, however, the rocks progressively assume a greater inclination, till at last, near a mural escarpment of granite, they assume a nearly vertical position ; the stratified arrangement of the sandstone also, which is in general perfectly distinct, becomes then very much obliterated, and the red colour of the strata entirely disappears. At the immediate junction of the sandstone and granite, which is only visible for about four feet, the former passes into a perfect granular quartz-rock ; the granite also exhibits characters completely different from those which it has when at a distance from the sandstone, and instead of being a distinct crystalline aggregate of quartz, felspar, and mica, it becomes a rock composed entirely of the two first, which are not arranged in distinct granular concretions, but, on the contrary, are blended intimately the one with the other. From the great thickness of the series of clay and chlorite slates, which in every part of Arran, with the exception of a short distance along the base of the hills which rise above Corry, lies always between the granite and the secondary rocks, it is vain to seek for junctions of the granite and the sandstone in other parts of the island. The one, however, which we were fortunate enough to find, though of limited extent, renders the fact that the granite has been protruded after the deposition of the sandstone sufficiently evident. In a paper published by Messrs Sedgwick and Murchison, in the Transactions of the Geological Society of London, "On

the Geological Relations of the Secondary Strata in the Island of Arran," it is stated "that the granite could not have been in a fluid state at the time of its elevation; for, had that been the case, it could never have risen into lofty mountains, and mural precipices, overhanging the secondary strata, without ever flowing over their broken edges, or penetrating their mass in the form of dykes." These reasons appear, however, in no way sufficient to prove that the granite of Arran has been elevated in a solid state, after its fluid protrusion through the primitive rocks with which it is connected. In regard to its having, unless elevated in a solid state, been unable to form mountains and mural precipices, we have a statement which may as well be applied to all the granite and trap rocks of Scotland, as to the granite of Arran, and indeed to almost every igneous rock which does not occur in streams. Concerning the circumstances which have allowed the granite and trap to assume their existing forms, this is no place for a discussion; and besides, they will suggest themselves on reflection to any geologist. Data are awanting also to prove, either that the granite does or does not penetrate the sandstone; and besides, the sandstone is so related to the granite that it might be older than it, and still not be traversed by veins; for, as we have just stated, the granite is, with one exception, always separated from the secondary rocks by a great formation of slate, consequently it might easily happen, that the plutonic rock might be newer than both, and still might have not sent out veins of a length sufficient to invade the secondary series. The nature of the ground, however, where a solitary instance of the sandstone being in contact with the granite may be observed, is such as to render it impossible to affirm whether the sandstone is crossed by granite dykes or not.

GEOLOGICAL MAP OF THE LOTHIANS.

In this map the several formations are laid down with an accuracy as perfect as the nature of the ground allowed us to do; the dotted lines which separate the formations being intended to express their limits in a general way.

In regard to the Red Sandstone deposits, we wish to state that several others occur in the Lothians, in addition to those which we have marked on the map; these, however, from being on a small scale, and existing only as deposits subordinate to the white sandstone series, we considered it unnecessary to exhibit; in many instances, also, their extent of distribution, when compared with the scale of the map, rendered this impossible. Several trap-dykes have, for the same reason, been excluded; a few, however, have been represented, though on a larger scale than that of the map.

The limestone which occurs in the Lothians we have only laid down on those parts where it is quarried or otherwise exposed at the surface. Without much chance of mistake, however, we might have connected many of these. When the covered state of the country, however, prevented us from being able to connect the limestones exposed by natural or artificial means, we have coloured the intervening portions, as the white sandstone series, from a knowledge that if limestone did not form the uppermost rock continuously, it was in almost every instance covered only by that group of strata.

By straight lines we have indicated the direction of the strata, and, by an arrow placed at right angles to these lines, the point of the compass to which they dip. In several instances we might perhaps have drawn lines shewing the outgoing of a stratum over a very considerable

space: this, however, we refrained from doing, as the apparent accuracy might in many instances have been found by other observers to have no existence. Vertical strata are denoted by a line shewing the direction, and by this mark +.

PLATE Explanatory of the colours used in the sections.

PLATE I. Fig. 1.—Unconformable position of the red sandstone and transition strata. Heriot Water, Berwickshire.

Fig. 2.—Section near Red Heugh exhibiting the same appearances.

II. Fig. 1.—Sectional view of another junction of the transition and secondary rocks, near Red Heugh.

Fig. 2.—Ground plan affording the same appearances. Red Heugh.

III. Fig. 1.—Greenstone traversing and overlying sandstone. St Leonard's Hill.

Fig. 2.—Greenstone enveloping masses of sandstone and overlying arenaceous limestone. Salisbury Crags. (The masses of sandstone are on a larger scale than the rest of the section.)

Fig. 3.—Greenstone overlying and fracturing arenaceous limestone. Salisbury Crags.

IV. Section of the central part of Salisbury Crags. Here the greenstone is found to have both contorted and enveloped masses of the sandstone. Upraised strata of sandstone are also found overlying it.

V. Fig 1.—Shift in sandstone. Cat Nick, Salisbury Crags.

Fig. 2.—Vein of greenstone traversing the greenstone and sandstone of Salisbury Crags. This point is one of the few in the Lothians where there are indications that the trap-rocks of the district are the formation of more than one epoch.

VI. Fig. 1.—Sectional view of the northern part of Salisbury Crags.

Fig. 2.—Greenstone porphyry overlying and enveloping strata of white sandstone. Northern front of Arthur Seat.

VII. Fig. 1.—Sectional view of Arthur Seat, partly ideal.

Fig. 2.—Section shewing the probable relations of the basalt which forms the summit of Arthur Seat, to the greenstone and sandstone of Salisbury Crags.

Fig. 3.—Section from the Calton Hill to Leith. (The greenstone rocks of Lochend and Restalrig are on a larger scale than the rest of the section.)

VIII. Fig. 1.—Greenstone traversing shale. St George's Well, Water of Leith.

Fig. 2.—Ground plan of greenstone vein traversing shale. St George's Well, Water of Leith.

PLATE VIII. Fig. 3.—Greenstone traversing sandstone; Bell's Mills, Water of Leith. (Sir J. Hall made the first of his interesting experiments in regard to slow refrigeration on specimens of this rock.)

IX. Greenstone enveloping masses of slate and sandstone. Hound Point.

X. Fig. 1.—Felspar vein traversing sandstone and passing into greenstone. Inch Colm.

Fig. 2.—Vein of greenstone traversing sandstone conglomerate. Cairn Muir.

Fig. 3.—Greenstone traversing and overlying red sandstone. Sunnyside Quarry.

Fig. 4.—Junction of greenstone and red sandstone. Whitberry Point.

XI. Fig. 1.—Greenstone traversing aud enveloping masses of red sandstone. Dunbar Castle.

Fig. 2.—Greenstone dyke traversing sandstone; near Broxmouth.

XII. Fig. 1.—Trap-veins traversing sandstone conglomerate. Stotan Cleugh.

Fig. 2.—Felspar veins traversing greywacke. Fassney Water.

Fig. 3.—Trap overlying strata of mountain limestone and trap-tufa. Kirkton, Bathgate.

XIII. Fig. 1.—Greenstone traversing sandstone and enveloping slate-clay. Winchburgh.

Fig. 2.—Greenstone traversing and overlying sandstone. Winchburgh.

XIV. Greenstone cliff near the harbour of Aberdour, in which are enveloped masses of sandstone and slate-clay.

XV. Fig. 1.—Greenstone traversing sandstone and shale, near Alexander's Crag.

Fig. 2.—Felspar vein traversing the coal series. Whinny Hill.

XVI. Strata of sandstone and limestone traversed by a vein of felspar and overlaid by greenstone. Tyrie near Kirkaldy.

INDICES.

GENERAL INDEX.

Explanation

OF THE COLOURS

STRATIFIED ROCKS.

- Greywacke
- Red Sandstone
- White Sandstone
- Mountain Limestone
- Slate Clay and Bit. Shale
- Arenaceous Limestone
- Coal

UNSTRATIFIED ROCKS.

- Greenstone
- Basalt
- Porphyry Series
- Trap Tufa

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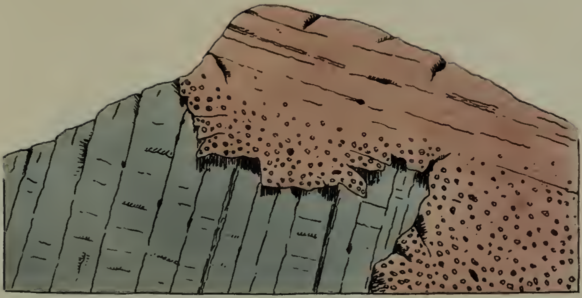
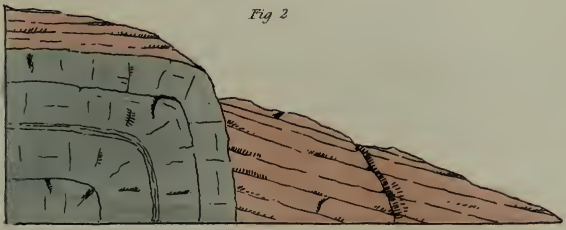
Fig 1



Junction of Greywackè and Red Sandstone Heriot Water.

Fig 2



Junction of Greywackè and Red Sandstone near Red Heugh.

Drawn & etched by R. J. H. Cunningham.

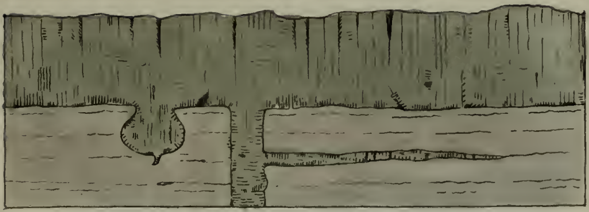
Junction of Greywacke and Red Sandstone — Near Red Heugh.

Ground Plan of a Junction of Greywacke and Red Sandstone — near Red Heugh.

Drawn & Etched by R.J.H. Cunningham.

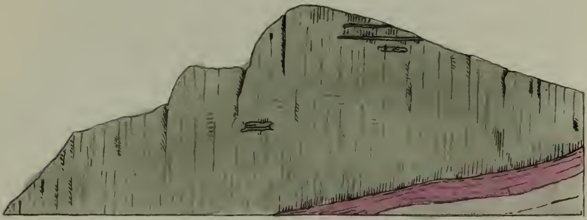
PLATE III

Fig 1



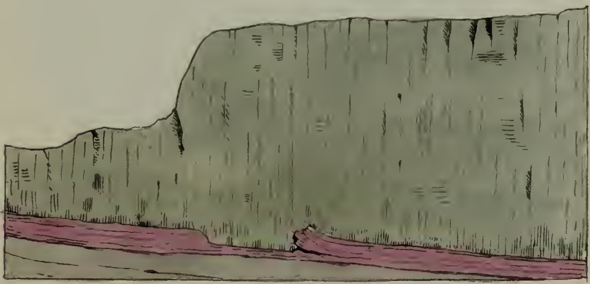
Junction of Greenstone and Sandstone S.t Leonards Hill.

Fig 2



Junction of Greenstone and Arenaceous Limestone Salisbury Craigs.

Fig 3



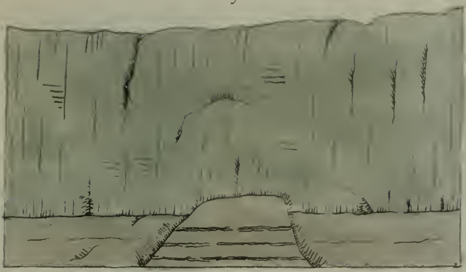
Junction of Greenstone and Arenaceous Limestone Salisbury Craigs.

Drawn &etched by R.J.H Cunningham.

Junction of Greenstone and Sandstone Salisbury Craigs.

Drawn & etched by R. J. H. Cunningham

Fig 1.



Shift in Sandstone. Salisbury Crags.

Fig 2.

Vein of Greenstone traversing Greenstone.
Salisbury Crags.

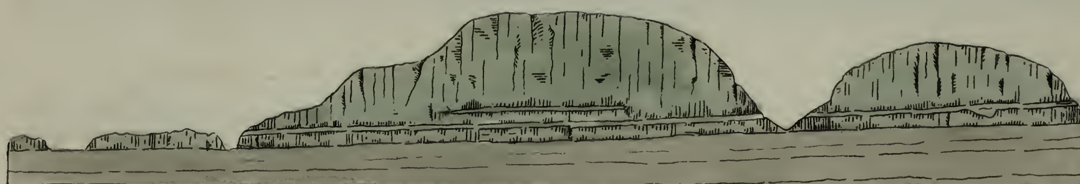
Drawn & etched by R. J. H. Cunningham.

Wern. Mem. Vol. VII.

Fig 1.

Sectional View of the Northern Part of Salisbury Crags.

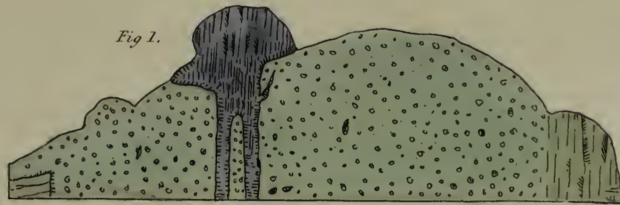
Fig 2.



Junction of Sandstone & Greenstone Porphyry, Arthur Seat.

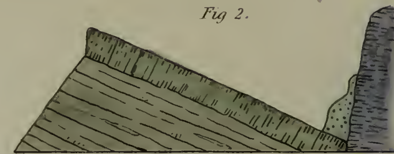
Drawn & etched by R.J.H. Cunningham.

Fig 1.



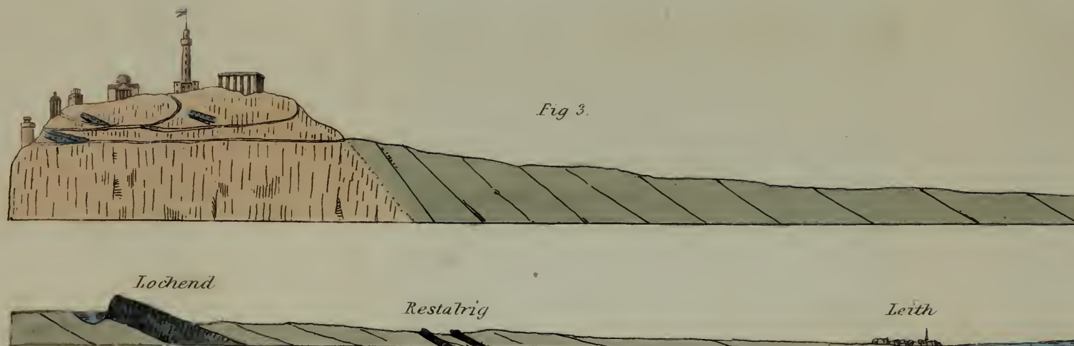
Section of Arthur Seat partly ideal.

Fig 2.



Section Shewing the probable relations of the Basalt of Arthur Seat, to the Greenstone of Salisbury Crags.

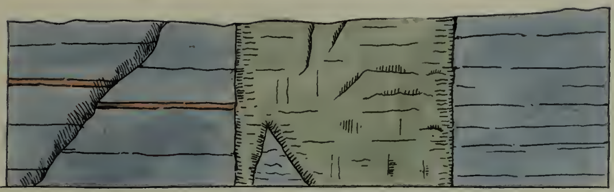
Fig 3.



Section from the Calton Hill to Leith

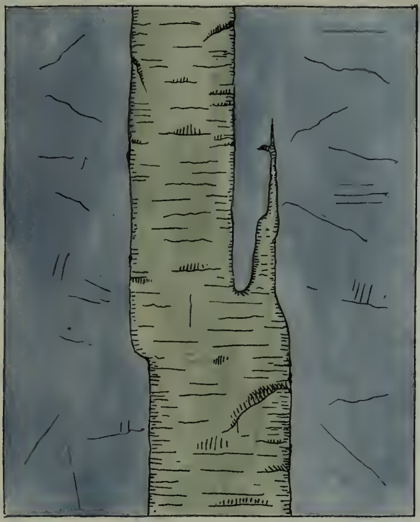
Drawn & etched by R.J.H. Cunningham.

Fig 1.



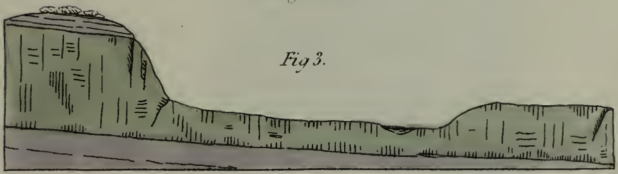
Greenstone traversing Shale. Water of Leith.

Fig 2.



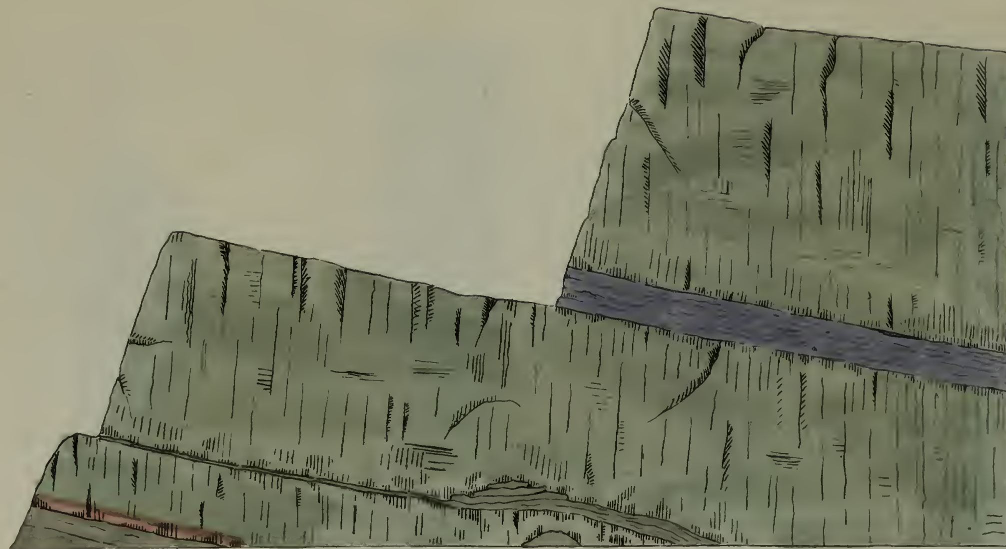
Ground plan of Greenstone vein traversing Shale.
Water of Leith.

Fig 3.



Greenstone vein_Bells Mills.

Drawn & etched by R. J. H. Cunningham.



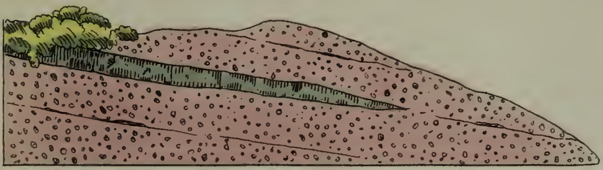
Greenstone enveloping Masses of Slate and Sandstone. Hound Point.

Drawn & etched by R. J. H. Cunningham.

Fig 1.

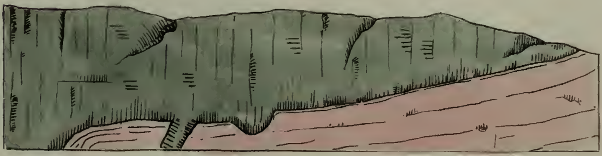
Felspar vein traversing Sandstone and passing into Greenstone_Inch Colm.

Fig 2.



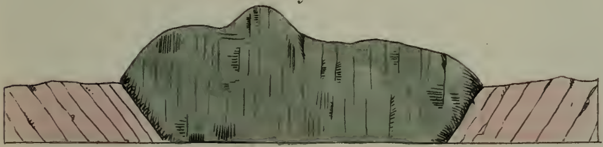
Vein of Greenstone traversing Sandstone Conglomerate_ Cairn Muir.

Fig 3.



Junction of Greenstone and Red Sandstone_ Sunnyside Quarry.

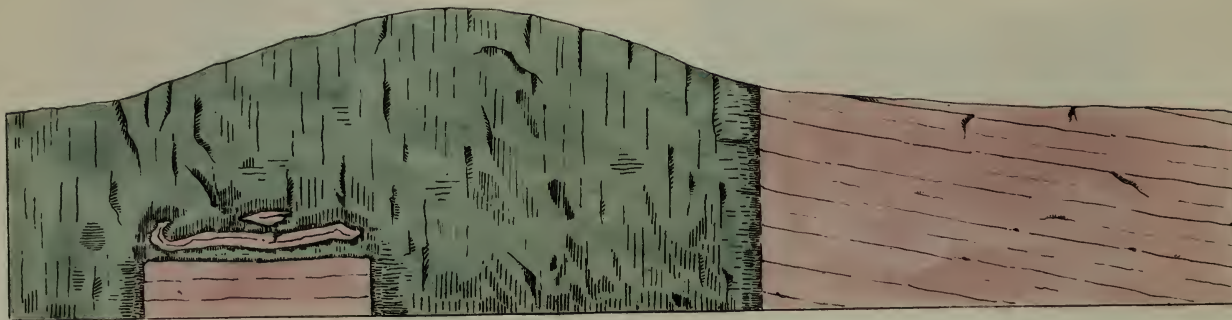
Fig 4.



Junction of Greenstone and Red Sandstone._ Whitberry Point.

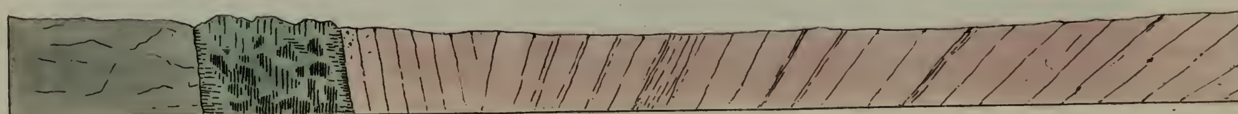
Drawn & etched by R.J.H. Cunningham.

Fig 1.



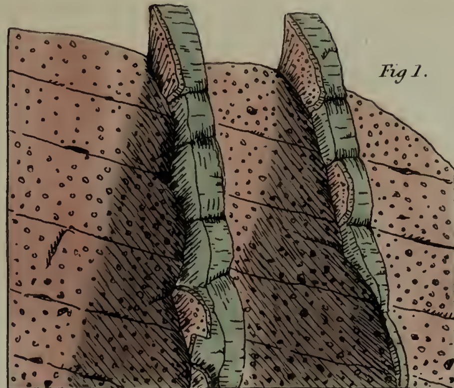
Greenstone traversing Red Sandstone – Dunbar Castle.

Fig 2.



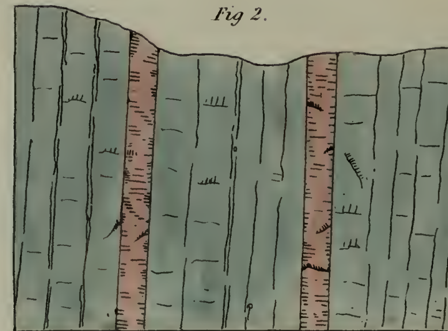
Greenstone traversing Sandstone – near Broxmouth.

Fig 1.



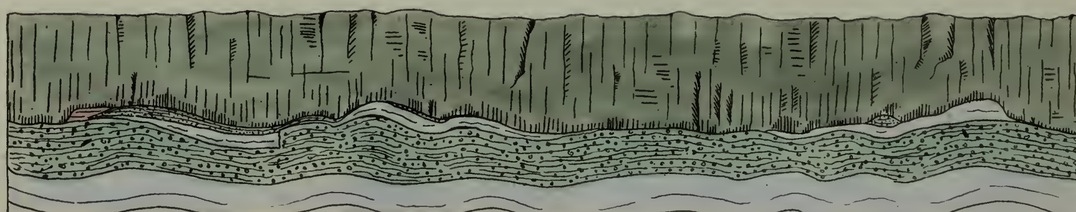
Trap veins traversing Sandstone Conglomerate.–Stotan Cleugh.

Fig 2.



Felspar veins traversing Greywackè.– Fassney Water.

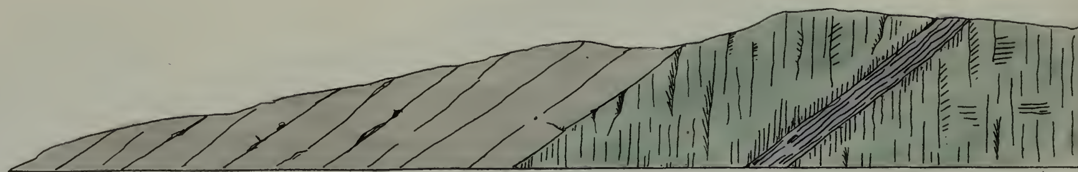
Fig 3.



Junction of Trap Tuffa and M. Limestone.– Kirkton. Bathgate.

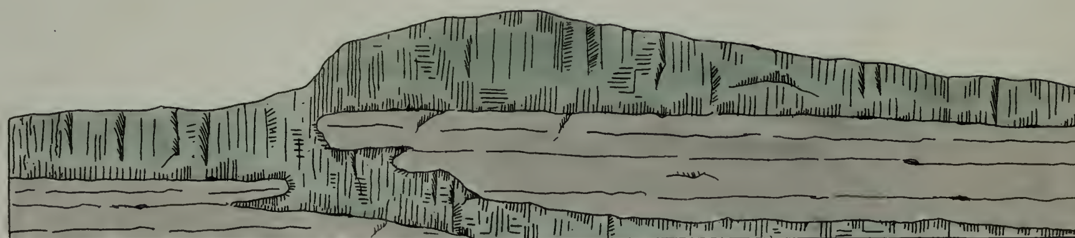
Drawn & etched by R. J. H. Cunningham.

Fig 1.



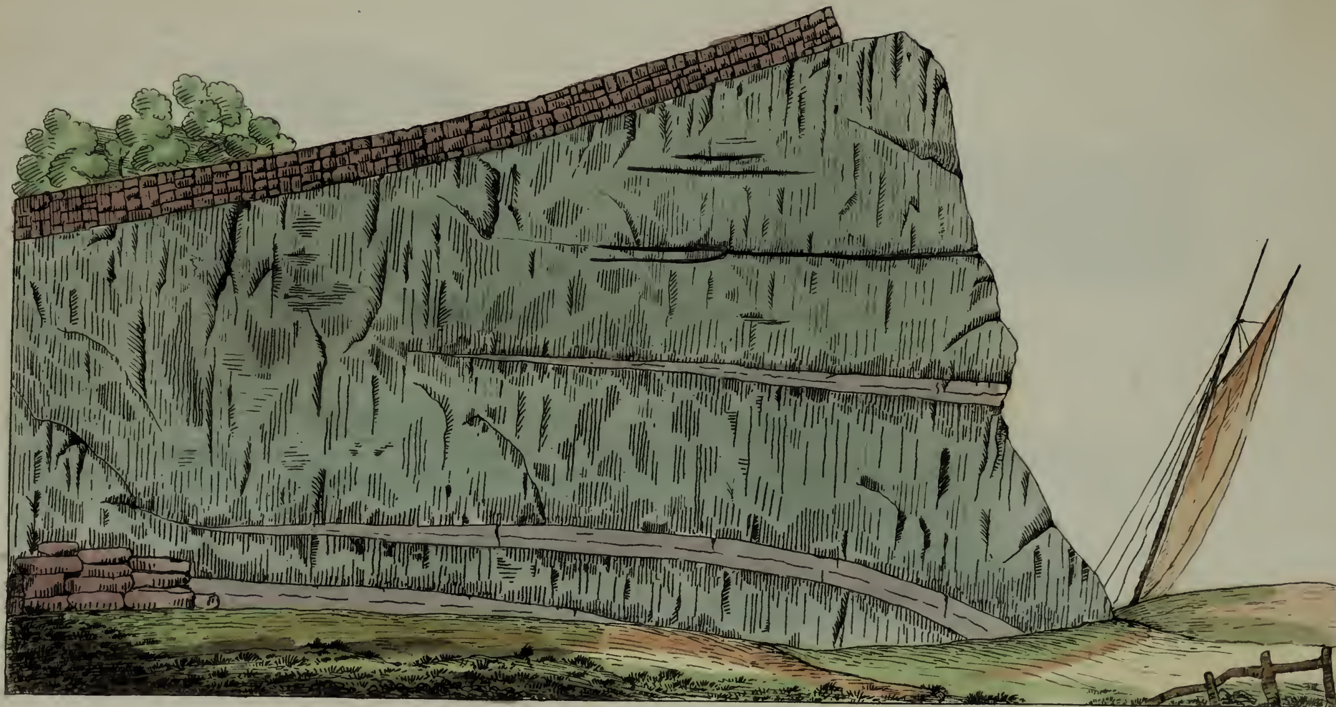
Junction of Greenstone with Sandstone and Slate Clay. Winchburgh.

Fig 2.



Junction of Greenstone and Sandstone. _ Winchburgh.

Drawn & etched by R. J. H. Cunningham.



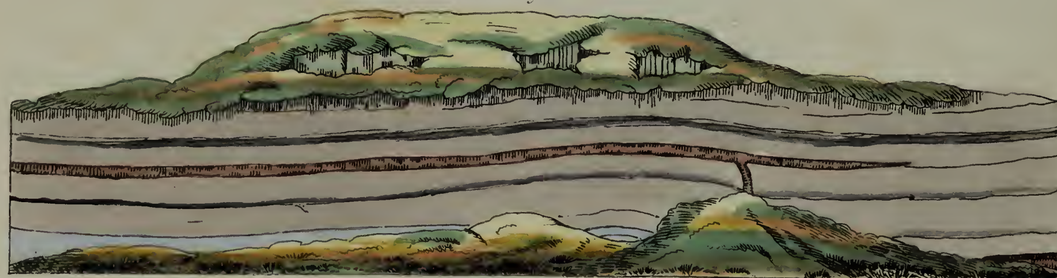
Sandstone and Slate enveloped in Greenstone.— Aberdour Harbour.

Drawn & etched by R.J.H. Cunningham

Fig 1.

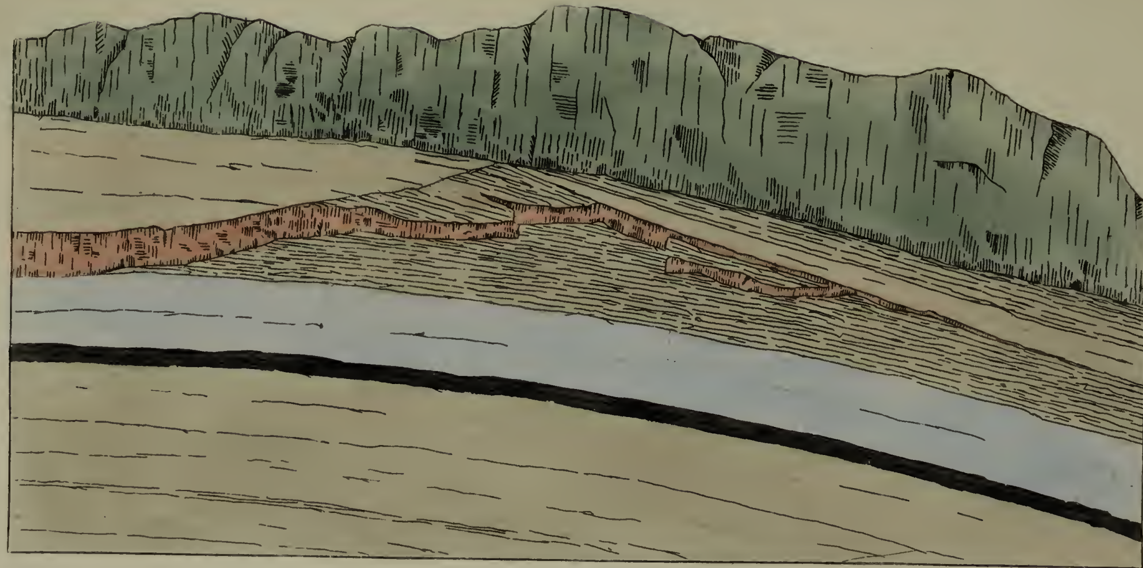
Junction of Sandstone and Shale with Greenstone near Alexanders Crag.

Fig 2.



Felspar vein traversing the Coal Series. Whinny Hill.

Drawn & etched by R.J.H. Cunningham.



Junction of Greenstone and Sandstone. Shore near Kirkaldy.

Drawn & etched by R.J.H. Cunningham

The sketch is not very correct – the bottom of the Greenstone is too straight